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The Effect of pH and Concentration on the Textural and Rheological Properties of Egg Albumin Foams

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ABSTRACT

The effect of different concentrations (i.e. 0.1% - 1%) and pH (7.0 and 4.0) on the textural/physical and rheological properties of egg albumin foams was investigated. The findings indicated that the stability and overrun of the foams were higher in the case of the foams made at pH = 4.0 and with the highest concentration of egg albumin (1%). The apparent viscosity of the albumin solution was significantly ($p<0.05$) higher at pH = 4.0 and in the presence of the higher concentrations of egg albumin (0.5% - 1%). All of the rheological parameters in amplitude sweep test indicated a weak structure of the foam made at pH = 7.0 and in the presence of a low concentration of egg albumin (0.1%). Regardless of the pH, the values for tan (δ) in the frequency sweep test indicated a weak biopolymer foam structure in the case of all samples. Yield stress was greater in the sample manufactured at pH = 4.0. Overall, the findings suggested that both protein concentration and pH had substantial effects on the rheological and physical properties of egg albumin foams.

KEYWORDS

Egg white albumin; Foam stability; Rheological properties; Physical properties; Yield stress

INTRODUCTION

Foams are the systems containing air phase stabilized in a continuous phase [1]. Proteins are the well-known ingredients for manufacture and stabilization of foam systems. These molecules have a surface-active property due to the presence of both polar and non-polar regions simultaneously. The production and stabilization of foams happen by means of the adsorption of proteins and forming a film around air/gas bubbles [2]. In addition, the surface-active property of these molecules (i.e. proteins) can decrease the surface tension of the phases and lead to foam formation [3].

Proteins can increase the amount of the surface pressure and form a viscoelastic and cohesive film in the interface

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of air-water, which correspondingly, prevents the possible coalescence of the bubbles in the system [4]. Globular proteins such as albumins are widely used in the production of the food-based foams. The partial unfolding of these proteins is important for foaming properties, because by this way, more hydrophobic groups are introduced on the surface. Such increase in the hydrophobicity of the surface can lead to a rise in the amphiphilic nature and flexibility, which can significantly improve various foaming properties including their rheological properties [5]. Among all, egg white albumin is a well-known globular protein for foam production. Egg albumin by itself includes a group of more than 40 different proteins [6], which may be classified into two groups; major proteins and minor proteins. Depending on the concentrations and functions, the major proteins in egg white include ovalbumin (about 54% of egg white proteins, 45 kD, isoelectric point (pI) of 4.5, and TD of 71.5°C - 84°C) that is a glyco phosphoprotein with excellent gelling and foaming properties, conalbumin (about 13% of egg white proteins, 77.7 kD - 80 kD, pI of 6 - 6.6, and TD of 57.3°C) that can bind metal ions and is considered as an antimicrobial protein, ovomucoid (about 11% of egg white proteins, 28 kD, pI of 3.9 - 4.3, and TD of 77°C) that is a heat-resistant protein in acidic conditions and a trypsin inhibitor, ovoglobulins (about 8% of egg white proteins, 30 kD - 49 kD, pI of 5.5 - 5.8, and TD of 92.5°C), which has a good foaming ability, ovomucin (about 3.5% of egg white proteins, 110 kD, pI of 4 - 4.5 and TD of 59.4°C - 71.3°C) that is a heat-resistant protein, and lysozyme (about 3.4% of egg white protein, 14.3 kD - 14.6 kD, pI of 10.7, and TD of 81.5°C), which belongs to the antimicrobial proteins. The minor groups of egg proteins include avidin, ovo inhibitor, CyStain, ovo glycoprotein, ovo macroglobulin, and ovo flavoprotein [7].

Foaming properties of egg white albumin are dependent of many parameters such as protein concentration, whipping time, pH (specifically, the pI), and the presence of hydrocolloids, sucrose, salt, etc. [7]. In particular, the concentration of protein can substantially affect the foamability and foam stability of the proteins, because this factor can change the rheological properties of the foam in the air-water interface, as well as the viscosity and surface tension of the protein solution [8]. The surface of each protein has a specified amount of net charge that depends on the amino acid composition, but it can change with pH. Proteins show a positive charge at the pH lower than their pI. The change of the net charge is due to protonation of glutamic and aspartic acid (acidic amino acids) [9]. Deprotonating of arginine, lysine, and histidine, the basic amino acids, alters the charge of proteins to negative when pH is higher than pI [9].

There has been a numerous amount of research carried out on the foaming properties of egg white proteins [10]. We have previously studied the foaming properties of EWA under the effect of basil seed gum [11] and ionic strength [12]. Our results showed that both ionic strength and BSG improved the rheological and foaming properties (in particular, foam stability) of egg white albumin. However, to the best of our knowledge, no systematic approach has been carried out in order to find out the optimum concentration of egg albumin combined with the effect of pH for production of the foams with the favorable rheological and textural properties during the storage of the foam systems. Many of the food products such as ice creams, chocolate mousses, marshmallows, and Chantilly are based on foam structure, and thus, understanding the structure of the foams, mechanism of foam instability, and the rheological properties of the foams in such foam-based products under different conditions (e.g. protein concentration and pH) is crucial [1]. Hence, the objective of this study was to find out the effects of different concentrations (0.1% - 1%) of egg albumin combined with the effect of pH (pH = 4.0 and 7.0 as the pH lower and higher than pI of the protein, respectively) on the rheological and physical properties of egg albumin foams during storage. In foam-based food products, overrun and stability of the foam are the most important parameters, and therefore, the products with high foamability and foam stability are desirable. Because, such properties have substantial effects on the important food properties such as stability, viscosity, texture, and mouthfeel.

MATERIALS AND METHODS

Manufacture of Egg Albumin Solutions and Foams

Egg white albumin powder (analytical grade ovalbumin, >80% purity, CS: 35021190) was purchased from Applichem (Darmstadt, Germany) and the same product (i.e. from the same batch) was used for all of the experiments to minimize the variation. Albumin solutions were prepared at the concentrations of 0.1% - 1% (w/v) after the powder was hydrated in distilled water for 2 hours at 25°C under mechanical stirring (300 rpm). The equal amounts of each solution were placed in two different containers in triplicates and the pH was adjusted to either 7.0 or 4.0 using HCL (0.1 M - 1 M). These solutions were stored at 4°C for 2 hours, after which they were whipped with an electric mixer (Black & Decker, 250W) for 180 seconds in a glass container (diameter of 7 cm and height of 9 cm) and the fresh foam was manufactured.

Physical Properties of the Manufactured Foams

Foam drainage

The fresh foams (about 30 g) were placed in a metal net over a graduated cylinder and the drained liquid was collected and weighed periodically. The foam stability was evaluated in terms of the weight fraction of the drained liquid after 30 minutes, according to the method from Kampf, Martinez [13].

Foam overrun

Foam overrun was calculated according to the method from Hu, Liang [14] with some modification. 30 cc of each sample (solution) was used for the production of the foam and the fresh foam was transferred to a graduated cylinder. The foam overrun was calculated using the following equation (Equation 1):

$$\text{Foam Overrun} = \frac{V_F - V_0}{V_0} \times 100 \quad (1)$$

Where, V_F is the foam volume reached at the end of the whipping process, and V_0 is the initial volume of the sample.

Foam density

Foam density was determined according to a previously published method [15]. The fresh foam was transferred to a cylindrical container and the foam density was calculated according to (Equation 2):

$$\text{Density } (g/cm^3) = \frac{m}{v} \times 100 \quad (2)$$

Where, m and v are weight (g) and volume (cm^3) of the foam, respectively.

Foam volume fraction

Foam volume fraction is the ratio of foam volume to the total volume (volume of both foam and liquid). Foam volume and liquid volume were recorded in a graduated cylinder at different times [16].

Rheological Properties of the Foams and Solutions

The rheological properties of the manufactured foams were measured with an Anton Paar Physica Rheometer (Physica, MCR 301, Anton Paar GmbH, Germany) equipped with a vane geometry (height of 3.8 cm and diameter of 1.9 cm) in four different parts. Amplitude sweep was the first test and it was measured in the strain region of 0.01% - 100%, 20°C, and 1 Hz. The amount of G′ (storage modulus), G″ (loss modulus), and tan (δ) were determined in the linear viscoelastic (LVE) region [17]. Moreover, the critical strain (γc), stress at the critical strain (τy), and the slope of the storage modulus in nonlinear viscoelastic (n-LVE) region were determined [17]. Subsequently, frequency sweep test was performed after the strain sweep test and the amount of

G′ and G″ were recorded in the range of the frequency of 0.1 Hz - 100 Hz in LVE region and at 20°C [18]. The amount of frequency dependency of G′ was determined by fitting frequency sweep data using power-law models as shown in the following equation (Equation 3):

$$G' = a.\omega^{b} \quad (3)$$

Where, ω is angular frequency (Rad/s), a (Pa.sn) is intercept, and b represents the slope of the frequency dependency of G' [19].

The yield stress was determined using the steady shear test. The amount of stress rose up continuously from 0.1 to 100 Pa at 20°C. The amount of the apparent viscosity versus shear stress was used for determination of yield stress. The amount of shear stress at maximum apparent viscosity was considered as yield stress [20]. Time sweep test was done at 20°C and during 30 minutes at a frequency of 1 Hz, where the storage and loss moduli were recorded.

The flow behavior of egg albumin solution was measured with a cup and bub geometry (26.63 mm, 40.0 mm, and 28.9 mm for bub diameter, gap length, and cup length, respectively). The flow measurement was done with increasing shear rate from 0.1 s^{-1} to 300 s^{-1} at 20°C [17].

Data Analysis

The experiments were carried out in triplicates and the statistical analyses were conducted using SPSS software (Version 16, IBM, Armonk, NY, USA). Duncan test was performed to determine the significant difference between the means of the measurements at the 5% probability level. Rheological data were analyzed using Rheoplus software (Version 3.4, Ostfildern, Germany) and graphs were plotted using Excel 2010 (Microsoft Redmond, VA, USA) or Sigmaplot (Version 12, San Jose, USA).

RESULTS

Foam Drainage

Liquid drainage occurs because of the gravity by draining the water present in the foam. The effect of different concentrations of egg albumin on liquid drainage of the foams at two different pH (7.0 and 4.0) during 30 minutes of storage is shown in (Figure 1). The results showed that the foam stability improved with the increase in the concentration of the protein (albumin). For example, at pH = 4.0 (Figure 1A), the amount of the foam drainage in the case of 0.1% egg albumin was 12.75 g and 20.31 g at Time 0 minute (immediately after transferring the mixture to the graduated cylinder, which is about 3 minutes after preparing the fresh foam) and Time 30 minutes, respectively. In the case of both pHs, the amount of the drainage decreased as egg albumin concentration increased (Figure 1A & Figure 1B). This parameter was 4.03 g and 12 g at Time 0 minute and Time 30 minutes, respectively, for the foam made with 1% egg albumin at pH = 4.0.

According to the numerous literature published about the stability of the foams made with different proteins [21,22], there are two possible mechanisms proposed in regard to the increase in foam stability: (1) the protein aggregates can adsorb at the interface and increase the interfacial viscoelasticity, by which the foam becomes more stable; (2) the aggregates which are not able to adsorb to the interface can increase a percolation process after they become limited into the foam films; this may result in the formation of a gel-like network, which in turn can be responsible for the reduction of liquid drainage [23]. An increase in the viscosity of the continuous phase can result in the decrease in foam drainage rates [24], which can be related to the increase in bulk viscosity, and therefore, delaying the rate of drainage in the manufactured foam.

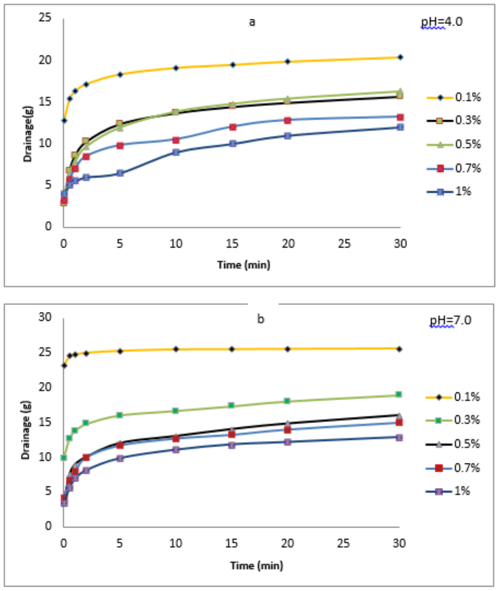

Figure 1: The effect of egg albumin concentration on the foam drainage at pH = 4.0 (A) and pH = 7.0 (B) during 30 minutes of storage.

In the case of the current experiment, in general, the foam drainage was lower at pH = 4.0 compared to pH = 7.0 (Figure 1A & Figure 1B). At pH close to pI (i.e. pH = 4.5), intermolecular repulsion of egg albumin is lower than pH = 7.0. This may lead to an improvement in the protein adsorption in the air-water interface and a decrease in the amount of drainage from the foam [25]. Our findings are in agreement with those reported by other researchers [26]. For example, Liang and Kristinsson (26) reported higher foam stabilities for the samples refolded at pH = 4.5 compared to the samples refolded at the other pH values. In addition, Yu and Damodaran [27] indicated that the foam stability was at its maximum point at pH close to pI, due to the minimum repulsion between proteins at pI that may result in the formation of a cohesive-viscous protein film at the interface.

Foam Overrun and Foam Density

The effect of egg albumin concentration combined with the effect of pH on foam overrun is shown in (Figure 2A). The findings demonstrated that the amount of foam overrun at pH = 7.0 increased with the increase in the concentration of egg albumin. The foam overrun was 52% and 362% when the concentration of the protein was 0.1% and 1%, respectively. The same trend was observed in the case of pH = 4.0; the highest overrun (405%) was observed in the foam made with the highest concentration of egg albumin (Figure 2A). Overrun for the sample manufactured at pH = 4.0 was higher than the sample manufactured at pH = 7.0. This is probably due to the fact that at pH = 4.0 (close to pI of albumin), there is a minimum intermolecular repulsion and higher protein adsorption at the air-water interface that results in a more foamability of egg albumin at this pH [25]. Other researchers [26-28] have also reported similar findings. Hammershøj, Prins [28] reported a higher bubble size and a lower foamability in egg albumen foam made at pH = 7.0 compared to the foam made at pH = 4.8 (close to pI).

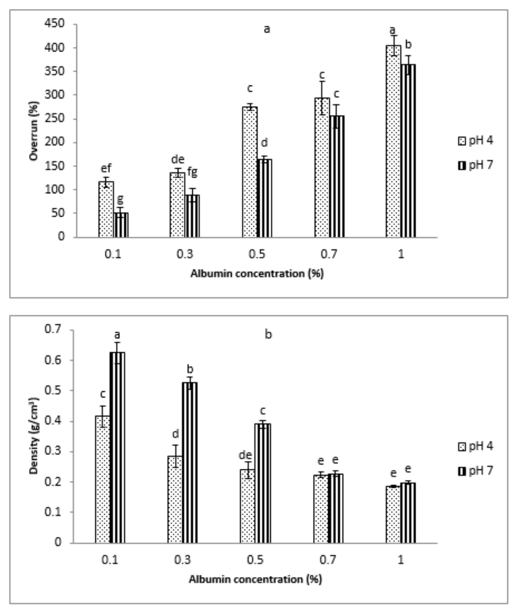

Figure 2: The effects of pH and the concentration of egg albumin on (A) Foam overrun and (B) Foam density.

Figure 2B presents the effects of the egg albumin concentration and pH on the foam density. The amount of density was 0.625 g/cm^3 for the sample containing 0.1% egg albumin and 0.198 g/cm^3 in the case of the foam containing 1% egg albumin (both at pH = 7.0), indicating a substantial decrease in the foam density with the increase in the concentration of egg albumin. A similar trend was also seen for the foams made at pH =

4.0 but with the same concentrations of the protein. The density at pH= 4.0 was 0.415 g/cm^3, 0.285 g/cm^3, 0.24 g/cm^3, 0.22 g/cm^3, and 0.186 g/cm^3 for the foams containing 0.1%, 0.3%, 0.5%, 0.7%, and 1% egg albumin, respectively.

Regarding the effect of pH, with the same concentration of protein, it can be said that the density of the manufactured foams was lower at pH = 4.0 than pH = 7.0. Previous studies have shown that foamability of several proteins could be improved at the pH close to their pI [29]. In the foam made at pH = 4.0, the electrostatic repulsion is lower than those made at pH = 7.0, as the pH close to pI of the protein can result in more foamability and foam stability of the corresponding protein [21]. Further, manufacturing the foam with the higher concentration of egg albumin forms thicker films around the bubbles and so can improve the rheological properties of the formed foam [29].

Foam Volume Fraction

The foam volume fraction is another important physical property of foam. The effect of egg albumin concentration and the pH on this parameter is shown in at both pH = 4.0 and pH = 7.0 is shown in (Figure 3). The foam volume fraction decreased during the 30 minutes storage in the case of all of the concentrations of egg albumin and for the foams made at both pH. This could be due to the bubbles joining each other in the foam structure as the time passes, which can lead to more liquid drainage. A positive relationship was observed between the increase in the concentration of egg albumin and the foam volume fraction, as this parameter was the highest for the foam made with 1% egg albumin and the lowest in the case of the foam made with the lowest concentration of egg albumin (0.1%) in the case of both pH. However, when the foams of the same concentrations of protein manufactured at the two different pH were compared with each other (Figure 3A & Figure 3B), the foams made at the lower pH (i.e. pH = 4.0) showed higher foam volume fraction values compared to those made at the higher pH (pH = 7.0). Like what was mentioned for the effect of pH on the other properties of the foams in the previous sections, the lower amount of foam volume fraction at pH = 4.0 could also be related to the low electrostatic repulsions occurring among egg albumin molecules at the pH close to pI, which can correspondingly result in an increase in the protein adsorption in the air-water interface, and accordingly, an increase in the formation of the bubbles in the foam structure [30]. At higher concentrations of egg albumin, a higher amount of the protein can be absorbed in the air-water interface, and thus, it can form a strong and viscous film around the newly formed bubbles, which can bring a higher foamability, stronger foam stability, and a bigger fraction of the foam volume.

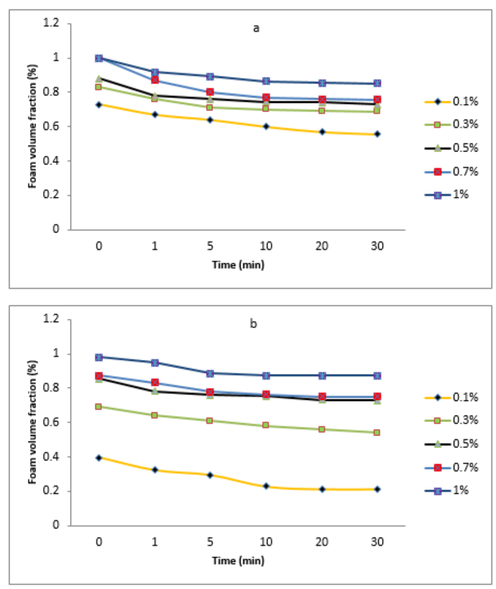

Figure 3: The effect of egg albumin concentration on the foam volume fraction at pH = 4.0 (A) and pH = 7.0 (B) during 30 minutes of storage.

The Flow Behavior of Egg Albumin Solutions

The flow behavior (shear stress; Pa) of different solutions of egg albumin at the two different pH (4.0 and 7.0) is presented in (Figure 4). These findings indicated that Pa of the albumin solutions increased with an increase in the concentration of albumin, although the behavior of solutions was different at different pH (Figure 4A &

Figure 4B). We also observed that the apparent viscosity of the albumin solutions decreased as Pa increased (data not shown), which is associated with the shear thinning behavior of the corresponding solutions.

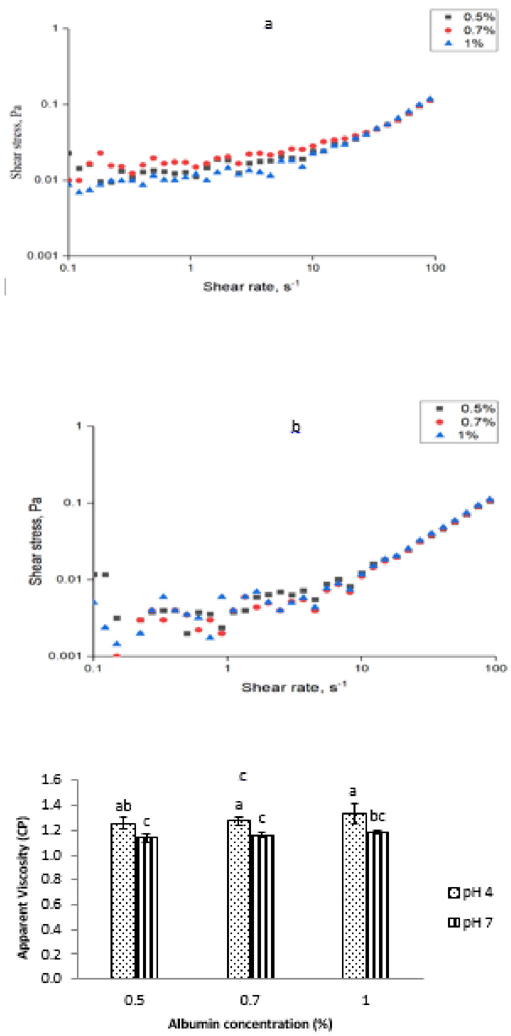

Figure 4: The flow behavior of different concentrations of egg albumin at pH = 4.0 (A) and 7.0 (B), as well as the apparent viscosity (C) of the solutions at different concentrations of the protein and different pH.

Such behavior might be attributed to the realignment of the polymer chains toward the flow side, something that can be a result of the reduction of the interactions between different polymers [31]. The results of the apparent viscosity for the solutions containing three different concentrations of egg albumin in a constant shear rate of 50 s^{-1} are also shown in (Figure 4C). Firstly, there was no significant increase ($p>0.05$) in the apparent viscosity of the solutions due to the increase in the concentration of egg albumin (Figure 4C). Secondly, egg albumin solutions at pH = 4.0 showed significantly ($p<0.05$) higher apparent viscosity than the solutions made at pH = 7.0 but containing the same concentrations of the protein. Singer, Yamamoto [32] reported that the apparent viscosity of some globular proteins (e.g. whey protein) increased in lower pH, due to the unfolding of the proteins, increase in hydrodynamic radii, and inter-entanglements of the proteins.

The Rheological Properties of the Foams

Due to the liquid drainage of the foams that occurs by Ostwald ripening and drainage, studying the rheological properties of weak foams are very difficult as the drained liquid can have a crucial impact upon the rheological properties of the manufactured foams [5]. Generally, a liquid film slip layer can form at the wall of the egg albumin foams and this may change the rheological properties of the manufactured foam. For this reason, there have been some techniques proposed in order to decrease the wall slip [5]. In this research, we report the findings obtained from the most popular rheological techniques as follows.

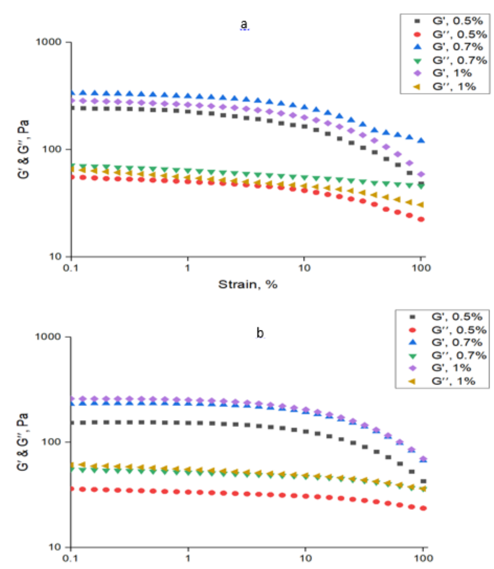

Figure 5: The storage and loss moduli (in amplitude sweep test) of the foams made with different concentrations of egg albumin at two different pH; 4.0 (A) and 7.0 (B).

Amplitude sweep

This test was performed in the range of 0.01% - 100% strain (20°C, 1 Hz) to define the LVE region of the foam samples, in order to help distinguish between the strong and weak structures of the foams. The strong structures represent higher values of LVE compared to weak structures [33]. We observed that the amount of G′ was more than G″ in the whole strain range, indicating a solid-like behavior for all of the samples (Figure 5).

For a better understanding, the extracted parameters from the amplitude sweep test are presented in (Table 1). In the case of this table (Table 1), γc is the critical strain and shows the amount of LVE region. Regardless of the pH, this parameter was higher when the concentration of egg albumin was 1%, which means this foam had a stronger structure (LVE = 0.063 and 0.08% at pH = 4.0 and pH = 7.0, respectively). τf indicates the amount of the shear stress at the end of LVE region, after which the structure begins to rupture [18]. At pH = 4.0, the values for this parameter were 0.119 Pa, 0.140 Pa, and 0.189 Pa for the egg albumin concentrations of 0.5%, 0.7%, and 1%, respectively, confirming that increasing egg albumin concentration has resulted in an increase in the amount of τf at pH = 4.0. The same trend was observed in the case of the foams made at a higher pH (7.0) but with the same concentrations of the protein.

pH	Albumin concentration (%)	G'_{LVE} (Pa)	G''_{LVE} (Pa)	Tan $(\delta)_{LVE}$	τ_f(Pa)	γ_c (%)	$G'_{s\,(n\text{-}LVE)}$	R^2
4.0	0.5	250.9 ± 35	57.7 ± 4.2	0.230 ± 0.06	0.119 ± 0.00	0.040 ± 0.01	-6.00	0.89
	0.7	344.0 ± 4.9	77.9 ± 1.5	0.227 ± 0.00	0.140 ± 0.02	0.040 ± 0.00	-6.83	0.88
	1	290.1 ± 10.6	65.3 ± 2.8	0.224 ± 0.00	0.189 ± 0.00	0.063 ± 0.00	-6.98	0.89
7.0	0.5	148.3 ± 1.4	37.0 ± 2.1	0.250 ± 0.01	0.046 ± 0.01	0.031 ± 0.00	-2.75	0.71
	0.7	225.7 ± 40.0	55.9 ± 1.1	0.248 ± 0.00	0.116 ± 0.02	0.05 ± 0.01	-4.50	0.75
	1	258.6 ± 36.2	62.9 ± 1.1	0.243 ± 0.00	0.213 ± 0.04	0.08 ± 0.03	-5.88	0.83

Table 1: The rheological parameters of the manufactured foams, extracted from the amplitude sweep test.

As we know, G′LVE and G″LVE represent the amount of storage modulus and loss modulus in LVE region, respectively. In regard to the effect of egg albumin concentration, the lower concentration tested in the current experiment (i.e. 0.5%) showed the lowest values for both G′LVE and G″LVE, which is an indication of a weak structure of the foam made at this concentration at both experimental pH (4.0 and 7.0). Tan (δ) LVE that is calculated from the ratio of G″ to G′ in LVE region, predicts the physical properties of the foam sample; the higher amount of tan (δ) LVE presents a viscose behavior of the sample. In the current study, tan (δ) LVE decreased as a result of the increase in the concentration of egg albumin so that it was 0.230, 0.227, and 0.224 for the foams made with 0.5%, 0.7%, and 1% egg albumin, respectively, at pH = 4.0, and 0.250, 0.248, and 0.243, respectively, for the foams made with the same concentrations of protein but at pH = 7.0. Thus, according to these results, the sample made with the highest concentration of egg albumin (1%) at pH = 4.0 represented the strongest foam structure compared to the other two samples made with 0.5% and 0.7% egg albumin. The slopes of G′ in the nonlinear region of the amplitude sweep test were calculated using the linear model. G′s(n-LVE) increased as egg albumin increased, which means that the foams prepared with the higher amounts of egg albumin showed a faster breakdown in the high amount of strain. Overall, it appears that the foams produced with the higher concentrations of egg albumin showed more favorable rheological properties. This may be explained by the formation of a network across the lamella, which can protect the bubbles from instability mechanism [34].

Frequency sweep and time sweep tests

The rheological parameters extracted from frequency sweep data are given in (Table 2). The dependency of G′ to frequency was described by Power-law model using Equation 3. The G′ was greater than G″ at low frequency but both parameters crossed over each other at high frequency (Figure 6).

The rheological parameters were compared at the constant frequency of 1 Hz. The G′ values ranged from 208.5 Pa to 270 Pa at pH = 4.0 and from 145.5 Pa to 180 Pa at pH = 7.0. G″ was in the range of 39.8 to 55.1 Pa for the foams made at pH = 4.0 and 27.8 Pa to 31.85 Pa for the foams made at pH = 7.0. Tan (δ) presented the values of 0.190 to 0.223 in the case of the foams manufactured at pH = 4.0 and 0.18 to 0.2 in the case of the foams made at pH = 7.0. This range of tan (δ) indicates a weak biopolymer structure [15]. The lowest amount of tan (δ) was observed for the foams made with higher concentrations of egg albumin, which shows a stronger structure of the foam in these samples [33]. Sadahira, Rodrigues [15] reported that the fresh foams manufactured using a mixture of egg white albumin and pectin showed a viscose behavior, but an elastic behavior appeared after storing such foams for 24 hours.

pH	4								7							
Albumin concentration (%)	G′= k′.ωn′			1 Hz					G′= k′.ωn′			1 Hz				
	k′, Pa.sn	n′	R2	G′, Pa	G″, Pa	η*, Pa.s	Tan (δ)	Crossover (%)	k′, Pa.sn	n′	R2	G′, Pa	G″, Pa	η*, Pa.sn	Tan (δ)	Crossover (%)
0.5	144.2	0.035	0.97	209	46.7	31.49	0.22	38.6	107.4	0.039	0.62	145	27.8	21.78	0.19	78.8
0.7	195.4	0.031	0.95	270	55.1	40.52	0.2	78.8	118.7	0.041	0.85	180	36.1	26.99	0.2	78.8
1	159.2	0.032	0.67	208	39.8	31.21	0.19	85	110.1	0.054	0.69	176	31.85	26.3	0.18	85

Table 2: The rheological parameters of the manufactured foams, extracted from the frequency sweep test at constant frequency of 1 Hz after fitting the storage modulus data using Power-law model.

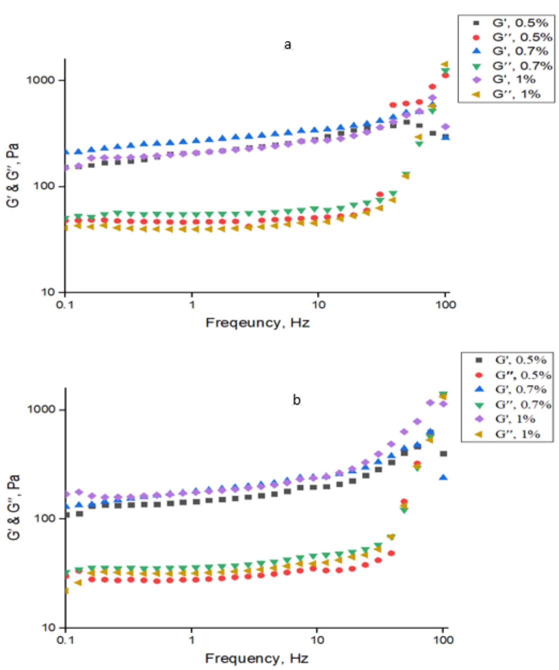

Figure 6: The storage and loss moduli (in frequency sweep test) of the foams made with different concentrations of egg albumin at two different pH; 4.0 (A) and 7.0 (B).

In regard to the frequency dependency of G′ using Power-law model, the amount of n′ was close to zero in the case of all of the foam samples, meaning that there was a low-frequency dependency for all of the manufactured foams [33]. Since a lower amount of n′ is an indication of a stronger structure, these results indicated that all of the manufactured foams possessed a strong structure.

The rheological properties of the manufactured foams made with different concentrations of egg albumin at pH = 4.0 and pH = 7.0 measured using the time sweep test (at a constant frequency of 1 Hz, 20°C and LVE region) are shown in (Figure 7).

Both G′ and G″ decreased irreversibly in the case of the foams made using any concentration of egg albumin and at either pH (4.0 or 7.0); however, the decrease was greater in the case of the foams made at pH = 4.0. Both

G′ and G″ showed higher values for the foams made with 1% egg albumin at both pH. The proteins such as egg albumin tend to be absorbed into the air-water interface and give a steric stabilization (same as electrostatic stabilization) to the foam structure.

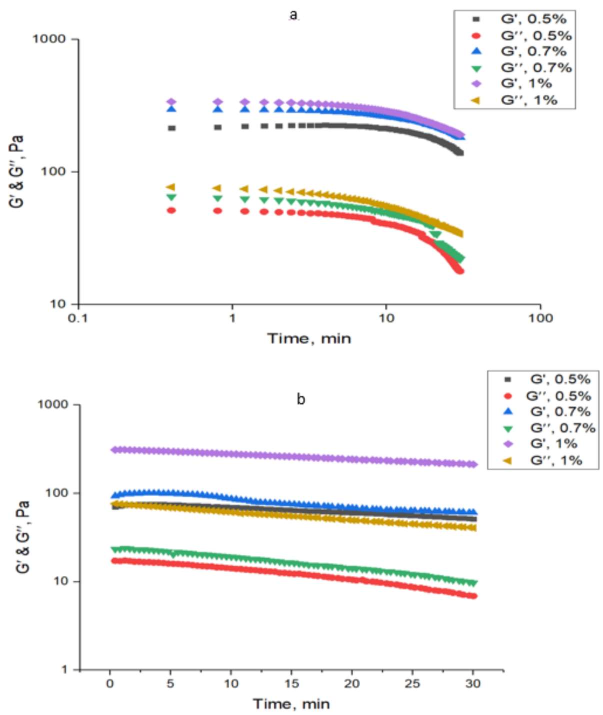

Figure 7: The storage and loss moduli (in time sweep test) of the foams made with different concentrations of egg albumin at two different pH; 4.0 (A) and 7.0 (B).

This absorbed film contains some significant structural coherence that can lead to higher surface rheological moduli by means of the interactions between the proteins that have been absorbed into the air-water interface. In higher concentrations of albumin, the protein can adsorb more rapidly at the air-water interface and form small bubbles, especially at pH = 4.0. In contrast, at the lower concentration of the protein, the small bubbles may merge together and form bigger bubbles, due to bubble coalescence. Compared to small bubbles, these big bubbles have lower stability so can destabilize rapidly in time sweep test and indicate the foam collapse.

Yield stress

Yield stress is considered as one of the most important rheological parameters, especially in the case of foam-based food products. Because, although these types of foods can endure a small degree of stress, they will flow under shear [5]. Of course, the structure of foams and foam-based foods has a crucial impact on such behavior. In the case of determination of the apparent yield stress, control stress rheology has more sensitivity than control rate rheology. In this way, the stress gradually increases to the materials and the yield occurs at the point of the first movement [35].

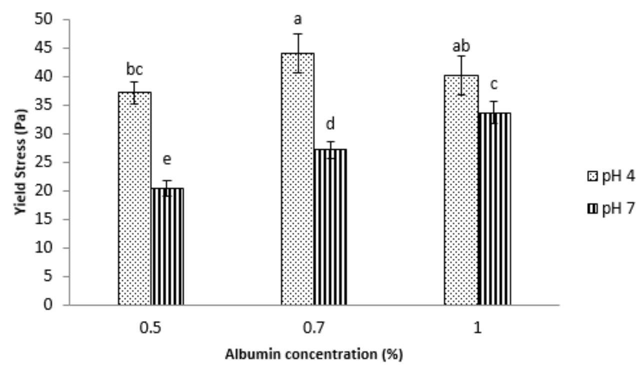

Figure 8: The effect of egg albumin concentration on the change of the yield stress versus shear stress of the foams manufactured at pH = 4.0 and pH = 7.0.

The effects of both albumin concentrations combined with the effect of pH on the amount of yield stress value are shown in (Figure 8). Yield stress values at pH = 4.0, were 37.12 Pa, 44.0 Pa, and 40.16 Pa for the concentrations of 0.5%, 0.7%, and 1% egg albumin, respectively. At pH = 7.0, the values for this parameter were 20.43 Pa, 27.13 Pa, and 33.63 Pa for 0.5%, 0.7%, and 1% egg albumin, respectively. Lexis and Willenbacher [34] reported that whey protein isolate (WPI) formed a network around the lamella at higher concentration (i.e. 1%) of WPI while it did not form such network at the low concentration (i.e. 0.1%) of the protein (WPI). This indicates better stability of the foams at higher concentrations of the proteins.

In the case of both pH, after the yield stress point, the apparent viscosity decreased (data not shown), which is probably related to instability of the foams via different mechanisms such as Ostwald ripening, drainage, and/or coalescence of the formed bubbles (34). Along these lines, Tabilo-Munizaga and Barbosa-Cánovas [35] recognized the yield stress as the abrupt point of the apparent viscosity. Liang and Kristinsson [26] reported that the foaming capacity, foam stability, and texture of the foams could be improved by treating egg albumin with some specific regimes such as the pH-induced unfolding and refolding.

CONCLUSION

In the current investigation, the effect of the concentration of egg albumin beside the effect of pH on the textural/physical and rheological properties of the foams was studied. Regardless of the pH, the increase in albumin concentration improved stability and foam overrun, while it decreased the density of the foams. However, the samples manufactured at pH = 4.0 showed better foam physical properties, compared to those made at pH = 7.0. PH also had a substantial effect on the structural flexibility of the protein, resulting in a better efficiency of proteins at the interface to form strong and viscous films, which in turns may lead to a higher foamability and foam stability of egg albumin. Taken together, the findings of this research represent the considerable effect of both protein concentration and pH on the rheological and physical properties of egg albumin foams. This information will be of significant use for the food industry and food research specialists in regard to foam-based food products, as it focuses on protein concentration and pH as two of the most important parameters that affect the texture of such food products.

REFERENCES

1. Miquelim JN, Lannes SC, Mezzenga R (2010) pH Influence on the stability of foams with protein-polysaccharide complexes at their interfaces. Food Hydrocolloids 24(4): 398-405.
2. Rouimi S, Schorsch C, Valentini C, et al. (2005) Foam stability and interfacial properties of milk protein-surfactant systems. Food Hydrocolloids 19(3): 467-478.
3. Benjamins J, Lucassen-Reynders EH (1998) Surface dilational rheology of proteins adsorbed at air/water and oil/water interfaces. In Studies in Interface Science 7: 341-384).
4. Nicorescu I, Vial C, Loisel C, et al. (2010) Influence of protein heat treatment on the continuous production of food foams. Food Research International 43(6): 1585-1593.
5. Mleko S, Kristinsson HG, Liang Y, et al. (2007) Rheological properties of foams generated from egg albumin after pH treatment. LWT-Food Science and Technology 40(5): 908-914.
6. Raikos V, Campbell L, Euston SR (2007) Effects of sucrose and sodium chloride on foaming properties of egg white proteins. Food Research International 40(3): 347-355.
7. Altalhi AS (2013) Egg white foam: A thesis presented in partial fulfilment of the requirements for the degree of Master of Food Technology at Massey University, Auckland, New Zealand (Doctoral dissertation, Massey University).
8. Patino J, Delgado M, Fernández J (1995) Stability and mechanical strength of aqueous foams containing food proteins. Colloids and Surfaces A: Physicochemical and Engineering Aspects 99(1): 65-78.
9. Langel U, Cravatt BF, Graslund A, et al. (2009) Introduction to peptides and proteins. CRC press.
10. Davis JP, Foegeding EA, Hansen FK (2004) Electrostatic effects on the yield stress of whey protein isolate foams. Colloids and Surfaces B: Biointerfaces 34(1): 13-23.
11. Razi S, Motamedzadegan A, Shahidi S, et al. (2018) Basil seed gum enhances the rheological and physical properties of egg albumin foams. Food & Nutrition Journal 8(6): 2575-7091.

12. Razi SM, Motamedzadegan A, Shahidi SA, et al. (2019) Physical and rheological properties of egg albumin foams are affected by ionic strength and basil seed gum supplementation. International Journal of Chemical Engineering 2019.
13. Kampf N, Martinez CG, Corradini MG, et al. (2003) Effect of two gums on the development, rheological properties and stability of egg albumen foams. Rheologica Acta 42(3): 259-268.
14. Hu Y, Liang H, Xu W, et al. (2016) Synergistic effects of small amounts of konjac glucomannan on functional properties of egg white protein. Food Hydrocolloids 52: 213-220.
15. Sadahira MS, Rodrigues MI, Akhtar M, et al. (2016) Effect of egg white protein-pectin electrostatic interactions in a high sugar content system on foaming and foam rheological properties. Food Hydrocolloids 58: 1-10.
16. Indrawati L, Wang Z, Narsimhan G, et al. (2008) Effect of processing parameters on foam formation using a continuous system with a mechanical whipper. Journal of Food Engineering 88(1): 65-74.
17. Razi SM, Motamedzadegan A, Matia-Merino L, et al. (2019) The effect of pH and high-pressure processing (HPP) on the rheological properties of egg white albumin and basil seed gum mixtures. Food Hydrocolloids 94: 399-410.
18. Razi SM, Motamedzadegan A, Shahidi A, et al. (2018) The effect of basil seed gum (BSG) on the rheological and physicochemical properties of heat-induced egg albumin gels. Food Hydrocolloids 82: 268-277.
19. Razavi SMA, Naji-Tabasi S (2017) Rheology and texture of basil seed gum: A new hydrocolloid source. In Advances in Food Rheology and its Applications: 405-435.
20. Carp DJ, Baeza RI, Bartholomai GB, et al. (2004) Impact of proteins-κ-carrageenan interactions on foam properties. LWT-Food Science and Technology 37(5): 573-580.
21. Damodaran S (1997) Protein-stabilized foams and emulsions. Food Science and Technology-New York-Marcel Dekker: 57-110.
22. Davis JP, Foegeding EA (2007) Comparisons of the foaming and interfacial properties of whey protein isolate and egg white proteins. Colloids and Surfaces B: Biointerfaces 54(2): 200-210.
23. Schmitt C, Bovay C, Rouvet M, et al. (2007) Whey protein soluble aggregates from heating with NaCl: Physicochemical, interfacial, and foaming properties. Langmuir 23(8): 4155-4166.
24. Hailing PJ, Walstra P (1981) Protein-stabilized foams and emulsions. Critical Reviews in Food Science & Nutrition 15(2): 155-203.
25. Macherey LN, Conforti FD, Eigel III W, et al. (2011) Use of *Mucor miehei* lipase to improve functional properties of yolk-contaminated egg whites. Journal of Food Science 76(4): C651-C655.
26. Liang Y, Kristinsson HG (2005) Influence of pH-Induced unfolding and refolding of egg albumen on its foaming properties. Journal of Food Science 70(3): C222-C230.
27. Yu MA, Damodaran S (1991) Kinetics of protein foam destabilization: Evaluation of a method using bovine serum albumin. Journal of Agricultural and Food Chemistry 39(9): 1555-1562.
28. Hammershøj M, Prins A, Qvist KB (1999) Influence of pH on surface properties of aqueous egg albumen solutions in relation to foaming behaviour. Journal of the Science of Food and Agriculture 79(6): 859-868.
29. Mita T, Ishida E, Matsumoto H (1978) Physicochemical studies on wheat protein foams. II. Relationship between bubble size and stability of foams prepared with gluten and gluten components. Journal of Colloid and Interface Science 64(1): 143-153.
30. Machado FF, Coimbra JS, Rojas EEG, et al. (2007) Solubility and density of egg white proteins: Effect of pH and saline concentration. LWT-food Science and Technology 40(7): 1304-1307.

31. Osano JP, Hosseini-Parvar SH, Matia-Merino L, et al. (2014) Emulsifying properties of a novel polysaccharide extracted from basil seed (*Ocimum bacilicum L*): Effect of polysaccharide and protein content. Food Hydrocolloids 37: 40-48.
32. Singer NS, Yamamoto S, Latella J, et al. (1988) Protein product base. US Patent 4,734,287.
33. Naji-Tabasi S, Razavi S (2017) New studies on basil (*Ocimum bacilicum L*) seed gum: Part III - Steady and dynamic shear rheology. Food Hydrocolloids 67: 243-250.
34. Lexis M, Willenbacher N (2014) Yield stress and elasticity of aqueous foams from protein and surfactant solutions–The role of continuous phase viscosity and interfacial properties. Colloids and Surfaces A: Physicochemical and Engineering Aspects 459: 177-185.
35. Tabilo-Munizaga G, Barbosa-Cánovas GV (2005) Rheology for the food industry. Journal of Food Engineering 67(1-2): 147-156.