

Basil Seed Gum Enhances the Rheological and Physical Properties of Egg Albumin Foams

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Abstract

The effect of Basil Seed Gum (BSG) on the rheological and physical properties of foams made of egg white albumin was investigated. The quadratic model was selected as a suitable statistic model for all responses. The increase in the BSG concentration from 0.1% to 0.6% (w/v) increased stability and density of the produced foam while it decreased drainage and overrun of the foams. Increase in albumin concentration from 0.3% to 0.5% (w/v) led to an increase in foam overrun, but a decrease in foam density. Storage modulus was greater than loss modulus at all frequency regions and both of these parameters increased because of the increase in frequency. Maximum $\tan(\delta)$ was observed at high concentrations of albumin and low concentration of BSG (0.5% and 0.1% w/v, respectively). Overall, it was found that BSG could be used for improving the stability of the foams in the food products containing egg white albumin

Keywords: Egg White Albumin; Foam Stability; Rheological Properties; Physical Properties; Yield Stress

containing proteins such as egg albumin.

Practical Applications

Foaming is one of the most important processing operations during manufacture of the foam-based food products such as ice cream, whipped cream, cakes, meringue, soufflés, mousse, and marshmallow. The application of Basil Seed Gum (BSG), as a natural and novel rich source of polysaccharides (e.g. glucomannan and glucan), has a great potential in various fields of food industry including foam-based food products containing proteins such as egg albumin. This gum possesses some great stabilizing and emulsifying properties, which make it as an important functional ingredient for increasing the foam stability and improving the foamability of the proteins in the foam-based food products. BSG can act as a foam stabilizer by increasing viscosity, surface activity, and gel-like behavior of the corresponding food systems. Thus, BSG can be used in the food industry as a natural additive to improve the structural and rheological properties of different foods

Introduction

Foams are complex systems in which the air phase is stabilized into the continuous phase [1]. The basic structure of the foams is associated with the surface-active agents such as proteins [2]. Foamability and foam stability are the two most important features of the foams produced by proteins. Foamability can be measured by the increase in foam volume, whereas, foam stability can be measured by the rate of the liquid drainage from foam or the rate of reduction in foam volume over time [3,4]. The most important reasons for the production of the foam-based food products include; decrease in food density and thus, decrease in calories per volume, increase in food volume, and improvement in textural, rheological, and sensorial properties of the food [5]. Currently, there are numerous food products based on foam structure, including; ice cream, chocolate mousse, meringue, and whipped cream [6]. Accordingly, the stability of foams in such products is indispensable as foam instability can lead to the

disintegration of the foams during the storage [7].

Egg white proteins are used widely in food industry as foaming agents [2]. Egg white has more than 40 different proteins with ovalbumin being as the most important constituents of these proteins [8]. This protein contributes to about 54% (w/w) of egg proteins with a molecular weight of 45 kDa and a pI (isoelectric point) of 4.5 and contains a disulfide bond [9]. Because of the instability in egg albumin foams, the foam made of egg albumin tends to destruct during the storage. For this reason, various stabilizers including different polysaccharide have been added to foam-based food products [1,5]. For example, Miquelim et al. (2010) [1] investigated the effect of different polysaccharides (e.g. guar, xanthan, and kappa-carrageenan) on the foam characteristic of egg albumin. These researchers reported that all of the aforementioned polysaccharides improved the foam stability of this protein. Therefore, it has been suggested that in order to improve foaming properties (in particular, foam stability) of egg albumin, in the foods containing egg albumin (e.g. mousses, marshmallow, and meringues), the addition of some stabilizing agents such as polysaccharides may be beneficial [1]. In this regard, polysaccharides can improve the long-term physicochemical stability of food proteins by affecting the rheological properties and network structure of their continuous phase [2]. Correspondingly, such interactions between proteins and polysaccharides can improve the synergistic characteristics of the food products and lead to the reduction of the manufacturing cost [8].

Basil Seed Gum (BSG) is a new hydrocolloid polysaccharide extracted from *Ocimum basilicum* L., stabilising and its emulsifying properties make it as an important functional ingredient for the food industry [10,11]. This gum is obtained from basil seed, a prevalent herb that is consumed in high quantity in culinary of different cuisines all over the world, due to its unique flavors [12]. The plant (basil), which is found in different regions of the world, especially in the tropical regions of Asia, Africa, and Central and South America, may also be consumed as a fresh herb and used for culinary purposes. In many parts of Asia (e.g. The Middle East), basil seed is used in beverages and ice desserts for aesthetic purposes as well as a source of dietary fiber. Basil seed is black in color and oval in shape with mean dimensions of about 3.10 mm in length, 1.80 mm in width, and 1.30 mm in height [10]. As there is a polysaccharide layer present in basil seed, when the seed is soaked in water, the outer pericarp swells into a gelatinous mass [13]. The polysaccharides in basil seed include two major fractions of glucomannan (43%) and (1-4)-linked xylan (24.29%), beside a minor fraction of glucans (2.31%) [14]. The presence of highly-branched arabinogalactan in addition to glucomannan and (1-4)-linked xylan (Azuma & Sakamoto, 2003) [13] makes BSG as an efficient stabilizing agent. BahramParvar and Goff (2013) [15] studied the effect of BSG in ice cream formulation and reported that BSG caused a different structure by reducing the amount of

the air in the structure of this foam-based product.

Response Surface Methodology (RSM) is a blend of statistic and mathematical techniques and is used to study the interaction effects of independent variables on responses [16]. For instance, Bag et al. (2011) [17] used RSM to optimize the process parameters for foaming of bael fruit pulp in order to acquire the maximum foam expansion and stability. Zheng et al. (2011) also used RSM to optimize process parameters such as microwave power, drying time, and pulp thickness for microwave-assisted foam from blackcurrant. Salahi et al. (2015) [18] used RSM technique for minimizing foam density and drainage volume of cantaloupe by changing the concentration of egg white powder, addition of xanthan gum, and changing the whipping time. Additions of polysaccharides such as BSG to protein solution may improve the foam properties of the proteins by increasing their viscosity and surface-active properties [2].

Optimum foaming properties and the foam stability not only modifies the microstructure of the corresponding food matrix, but also affects the mouthfeel properties of the food. This is due to some specific textural characters in different foam-based foods, for example, lightness in whipped cream, brittleness in confectionary, and scoopability in different mousses [19]. The main objectives of the present study included; a) to investigate the effect of BSG on physical and rheological properties of the foams made of egg white albumin (called 'egg albumin' in present study), and b) to find out the optimum concentration of both the protein (i.e. egg albumin) and the polysaccharide (i.e. BSG), as the effective parameters, in order to obtain the maximum foamability and foam stability.

Materials and Methods

Materials

Basil seeds were purchased from a local market in Neka, Iran. Albumin powder from chicken egg white (analytical grade ovalbumin, >80% purity, CS: 35021190) was obtained from AppliChem GmbH (Darmstadt, Germany). All other reagents and chemicals were from analytical grade.

Basil Seed Gum Extraction

Basil seed gum (MW: 2320 kDa) was extracted according to the method from Hosseini-Parvar et al. (2010) [10], at optimum conditions (i.e. 1 g of the seed in 65 mL water at pH= 8.0 and temperature of 68 °C), stirring for 20 min. The solution was then passed through a cheesecloth and frozen at -18 °C, before being freeze-dried (FDU, Operon, South Korea) and milled. Obtained BSG powder was packed in moisture impermeable plastic bags and maintained in a hermetic container (at 21 °C) before further analyses. The most important component of BSG that can substantially affect its functional properties is the amount of carbohydrate, so BSG from different varieties may result in different properties of the end product. BSG used in the current study contained 74% carbohydrates.

Preparation of the Solutions

BSG solutions, at concentrations of 0.1-0.6% (w/v), were prepared by adding appropriate amounts (as presented in Table 1) of BSG powder to deionized water. The solutions were then stirred for 2 h at room temperature (21 °C) and then overnight at 4 °C to complete the hydration. Albumin solutions (30 ml) were prepared at concentration of 0.3-0.5 % (w/v) by hydrating in deionized water for 2 h at 25 °C and under mechanical stirring. The solution was then kept at 4 °C for 12 h to complete solubilisation of the protein.

Independent variables	Coded values		
	-1	0	+0
A; Albumin (%)	0.3	0.4	0.5
B; Basil seed gum (%)	0.1	0.35	0.6

Series	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Albumin (%)	0.4	0.5	0.3	0.4	0.5	0.3	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.3
BSG ¹ (%)	0.35	0.1	0.6	0.35	0.35	0.1	0.35	0.35	0.350	0.6	0.6	0.1	0.35	0.35

¹Basil seed gum

Table 1: Independent variables and their level in the central composite design.

Foam Preparation

Glass beakers (250 mL) were used as containers to form the egg albumin foams. According to the experimental design (face-centered central composite), to prepare 30 ml of the samples, an appropriate amount of albumin and BSG solution (please see Table 1) were poured into the beaker. The mixture was then whipped with an electric mixer (Black & Decker, 250W, Maximum rpm) at ambient temperature for 180 seconds.

Foam Stability

Foam stability was studied by holding the foam for 30 min and comparing the obtained foam volume after this time with the initial foam volume at 0 min (Eq. 1).

$$\text{Foam stability} = \frac{V_{30}}{V_0} \quad (1)$$

where, V_{30} is the foam volume at 30 min and V_0 is the foam volume at 0 min [20].

Foam Overrun

Foam overrun was calculated according to the following equation (Eq. 2):

$$\text{Foam overrun} = \frac{V_F - V_0}{V_0} \times 100 \quad (2)$$

where, V_F is the foam volume at the end of whipping and V_0 is the initial volume of the sample [8].

Liquid Drainage

Liquid drainage was determined from the liquid drained from the foam in a 30-min period, according to Eq. 3 (Liang & Kristinsson, 2005).

$$\text{Liquid drainage} = 1 - \frac{V_i - V_{L30}}{V_i - V_{L0}} \quad (3)$$

where, V_i is the initial liquid volume, V_{L30} , indicates the volume of liquid at 30 min, and V_{L0} is the volume of liquid at 0 min [20].

Foam Density

The density of the foams was determined in terms of mass over volume and expressed in g/cm³. The foams were transferred very carefully to prevent the destruction of its structure and trapping the air voids were avoided while filling the cylinder [21].

Rheological Properties

The rheological properties of the foam samples were examined using an Anton Paar Physica Rheometer (Physica, MCR 301, Anton Paar GmbH, Germany), with a cone and plate geometry at (20 °C). The temperature of the bottom plate was controlled with a Peltier system (Viscotherm VT2, Phar Physica) to precisely control the temperature. Strain sweep tests elevated over a strain range of 0.01-1000% in a controlled rate mode and a constant frequency of 1 Hz, in order to determine the linear viscoelastic range [19].

Frequency sweep tests were performed within the LVE, in the range of 0.1-100 Hz (at 20 °C). The obtained mechanical spectra were characterized by the storage modulus (G'), loss modulus (G''), and the loss tangent ($\tan \delta$) as a function of frequency (Hz). All of the rheological measurements were carried out immediately after the preparation of the foams within a gap of 1 mm [5].

Experimental Design

To estimate the main effects of the process variables on the stability, density, overrun, drainage volume, and the rheological parameters of the albumin-BSG foams, RSM was used. The experiment was established based on a face-centered Central Composite Design (CCD). In this experimental design, three coded levels for each variable were selected; -1, 0, and +1, corresponding to the low level, mid-level, and high-level of each independent variable, respectively. The independent variables and representative coded and uncoded levels are given in Table 1. The experimental range was chosen on the basis of the results of pretreatment tests. The independent variables were consisted of albumin (0.3-0.5%, w/v), and BSG (0.1-0.6%, w/v) concentrations [18]. CCD generated 14 runs to investigate the effect of independent variables on physical properties of the foam. To avoid the systematic errors and unexplained variability, which may occur in the observed responses, experiments were replicated (six replications) in the center of the design [22]. To investigate the behavior of the response surfaces, a second-order polynomial equation (Eq. 4) was fitted to the experimental data of each independent variable, as presented below:

$$Y = \beta_0 + \sum_{i=1}^3 \beta_i X_i + \sum_{i=1}^3 \beta_{ii} X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{ij} X_i X_j \quad (4)$$

where, Y is the estimated response (i.e., foam density and drainage value), β_0 , β_i , β_{ii} , and β_{ij} are constant coefficients, and X_i and X_j represent the coded independent variables.

The adequacy of the regression model and the goodness of fit were determined by model analysis, lack-of-fit, and coefficient of determination parameters [23]. The response surfaces for these models were plotted as a function of two variables while keeping another variable at the average value. The surface graphic presentation of the response surface models, analysis of variance (ANOVA), and evaluation of the regression models were performed using Design-Expert (Version 7, Stat-Ease, Minneapolis, MN, USA) software.

Results and Discussion

The quadratic model was selected as a suitable statistic model for all responses. The coefficient of a model for all responses is shown in Table 2A, where it can be found that all of the parameters were fitted with quadratic model ($R^2 > 0.942$). Table 2B shows that lack-of-fit was not significant for this model at 95% confidence level, indicating that this model was adequately accurate for predicting the responses. Also, the model, BSG, and albumin concentration all had presented significant effects on the physical properties of the manufactured foam.

A

Parameter	Mean	STDEV ¹	C.V. ² (%)	R ²	Adjusted R ²	Predicted R ²
Stability (%)	0.93	0.026	2.75	0.953	0.945	0.926
Overrun (%)	59.24	9.12	15.39	0.964	0.954	0.917
Drainage	0.14	0.036	25.21	0.980	0.977	0.970
Density (g/cm ³)	0.61	0.035	5.74	0.951	0.942	0.903
¹ Standard deviation, ² Coefficient of variation						

B

Parameter	Source	Model	Albumin	BSG [†]	B2	Lack of Fit	Pure Error
Stability (%)	SOS	0.15	-	0.11	0.044	0.0032	0.0039
	Df	2	-	1	1	6	5
	MS	0.075	-	0.11	0.044	0.0005	0.0007
	F	113.3	-	160.1	66.51	0.68	-
	P Value	< 0.000	-	< 0.000	< 0.000	0.676	-

Overrun (%)	SOS	22674.95	785.85	20102.8	1786.22	638.18	192.76
	Df	3	1	1	1	5	5
	MS	7558.3	785.85	20102.8	1786.2	127.63	38.55
	F	90.96	9.457	241.92	21.496	3.31	-
	P Value	< 0.000	0.011	< 0.000	0.000	0.107	-
Drainage	SOS	0.71	-	0.49	0.22	0.0058	0.0081
	Df	2	-	1	1	6	5
	MS	0.35	-	0.49	0.22	0.0009	0.0016
	F	278.4	-	385	171.75	0.6	-
	P Value	< 0.000	-	< 0.000	< 0.000	< 0.000	0.724
Density (g/cm ³)	SOS	0.26	0.016	0.25	-	0.01	0.0033
	Df	2	1	1	-	6	5
	MS	0.13	0.016	0.25	-	0.0016	0.0006
	F	106.86	12.99	200.72	-	2.56	-
	P Value	< 0.000	0.004	< 0.000	-	0.161	-
†Basil seed gum							

Table 2: Coefficients of prediction model (A), and response surface plot for effects of BSG and albumin on foaming parameters (B).

Foam Stability and Drainage

Determination of foam stability is important and it is the key step in studying the main properties of the foam. According to Table 2B, it appears that the concentration of BSG beside the protein-gum concentration interaction presented a significant effect on stability of the manufactured foam ($p < 0.00$). The final empirical model in terms of coded factors that have a significant effect on stability is presented as following equation (Eq. 5):

$$\text{Stability} = +0.98 + 0.13 \times B - 0.11 \times B^2 \quad (5)$$

where, B is BSG concentration (g/100 g).

It can be understood that an increase in the positive coefficient (B) would lead to the increase of foam stability. Additionally, in contrast, any increase in the quadratic terms will cause a decrease in foam stability. The variation of stability with albumin and BSG

are graphically shown in the 3D surface plots in Figure 1A. It can be seen that increasing the BSG from 0.1% to 0.6% (w/v), increases the foam stability significantly ($P < 0.05$). One of the possibilities by which the foam stability might have improved (in the case of the current experiment), could be due to the possible increase in the viscosity, which can correspondingly prevent the formed bubbles from joining each other, and consequently, making the foam more stable. The rising viscosity of the aqueous phase by adding BSG might influence the viscoelastic properties and thickness of the adsorbed macromolecular layer which can decrease the thinning rate of lamella and improve the foam stability [24]. Thus, an increase in the foam stability can be related to the increase in bulk viscosity in the presence of BSG and the formation of the strong elastic film as a consequence of a possible biopolymer interaction at the interface, in agreement with the findings of [24].

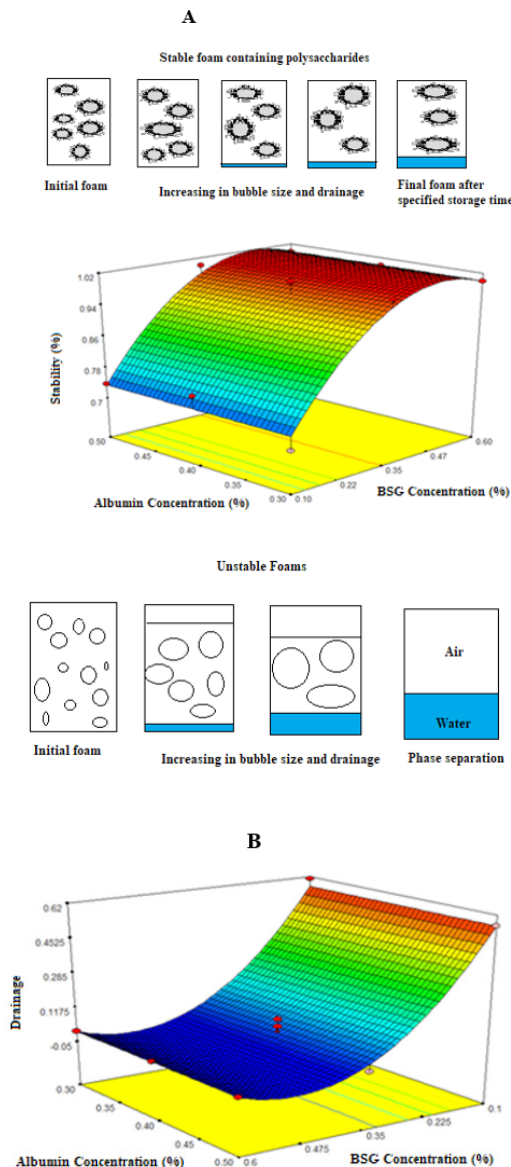


Figure 1: Effect of basil seed gum (BSG) in the combination with egg albumin on stability (A) and drainage (B) of the foams. The schematic stability mechanism is redrawn from [3].

The ANOVA for response surface reduced quadratic model is presented in Table 2A. As can be seen in this table (2B), gum concentration and the protein-gum concentration interaction showed significant effects on foam drainage ($p < 0.00$). The final empirical model in terms of the coded factors that have a significant effect on drainage is presented in Eq. 6 below:

$$\text{Drainage} = +0.033 - 0.29 \times B + 0.25 \times B^2 \quad (6)$$

where, B is the BSG concentration (g/100 g).

The variations of drainage of the albumin foams with different combinations of the process parameters are presented in the 3D surface plot in Figure 1B. Drainage is the liquid flow through foam driven by capillary forces or external forces such as gravity. Foam stability is influenced by the physical and rheological properties of the interface and the continuous phase. The thickness of the interface, foam size distribution, interface permeability, and the surface tension are effective on drainage value [18]. From Figure 1B, it can be observed that the addition of foam stabilizer (i.e. BSG) plays a significant role in the stability of the manufactured foams. The foams are more stable at high viscosity, because increasing the viscosity of the aqueous phase leads to the creation of a network structure in the bulk phase that would keep the interfacial wall from easily breaking, which causes improvement of the foam stability [25]. Some researchers [18,21]. Reported that increasing the protein content could reduce the drainage. Because, any increase in the concentration of the foaming agent may lead to some increase in the viscosity and yield stress of the continuous phase, and/or result in increasing the thickness and strength of the adsorbed films at the air-water interface. However, in the case of this study, albumin did not significantly ($P > 0.05$) impact upon the foam drainage.

Overrun and Density

The ANOVA analysis showed that the quadratic terms of BSG and albumin had a substantial effect on overrun (Table 2B). According to these results, albumin concentration, BSG concentration, and albumin-BSG concentration interaction significantly ($p < 0.00$) influenced the foam overrun. Empirical model in terms of the coded factors, that have a significant effect on overrun, was presented according to the following equation:

$$\text{Overrun} = +49.46 + 11.44 \times A - 57.88 \times B + 22.82 B^2 \quad (7)$$

where, A is albumin concentration (g/100 g) and B represents the BSG concentration (g/100 g).

The variations of overrun of the albumins foam with different combinations of the process parameters are graphically shown in the 3D surface plot (Figure 2A), where it can be observed that the addition of the foam stabilizer (BSG) plays a significant role in the overrun of foam. Increasing the concentration of BSG from 0.1% to 0.6% (w/v) led to a decrease in the foam overrun. On the other hand, as expected, increasing the concentration of albumin from 0.3% to 0.5% (w/v) led to an increase in the foam overrun. This improved functionality of the foam, which could be attributed to more absorption of the protein and its aggregation on the interfacial lamellae resulting in a decreased surface tension [26]. Damodaran

(1997) demonstrated that the rate at which a protein can reduce interfacial tension between water and air is the most important factor for foamability of the proteins. Wierenga et al. (2003) [27] showed that ovalbumin with higher exposed hydrophobicity reduced the kinetic barrier for its adsorption to the air/water interface. When BSG is added to any liquid, it can increase the viscosity of the liquid. The viscous liquid would prevent the trapping of air during whipping or mechanical mixing, which accordingly, can result in a reduction of the foam expansion [18].

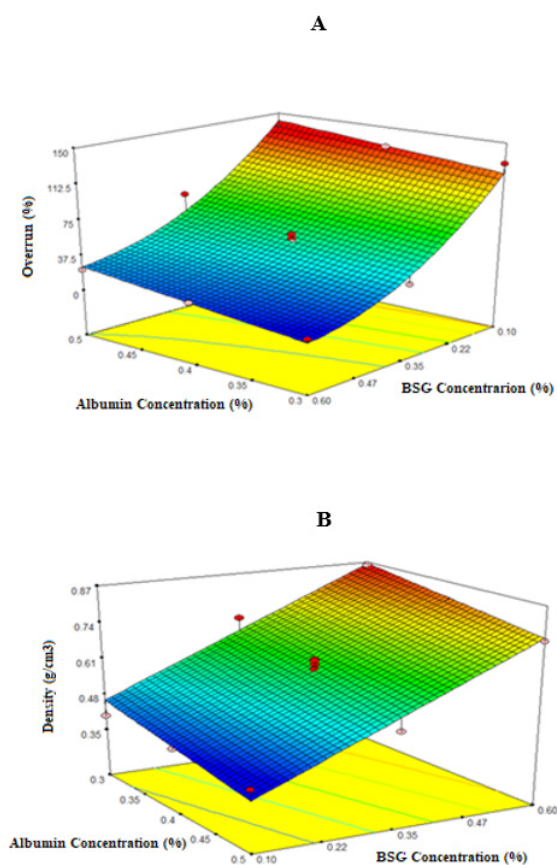


Figure 2: Effect of basil seed gum (BSG) in the combination with egg albumin on overrun (A) and density (B) of the foams.

The results of ANOVA for response surface reduced quadratic model of density are shown in Table 2B. It was found that while both albumin concentration and BSG concentration had significant effects on the foam density, the effect of protein-gum concentration interactions was not significant ($p>0.05$). The final empirical model in terms of the coded factors that have a significant effect on density is presented in the equation below (Eq. 8):

$$\text{Density} = +0.61 - 0.052 \times A + 0.2B \quad (8)$$

where, A is albumin concentration (g/100 g) and B is BSG concentration (g/100 g).

The variations of density of the albumin foams with different combinations of the process parameters are graphically shown in the 3D surface plot in Figure 2B. The foamability can simply be evaluated through the measurement of the foam density [28]. The higher amount of incorporated air during whipping caused the higher foam expansion [29]. It can be seen that increasing the concentration of albumin from 0.3% to 0.5% (w/v), can make the foam density to decrease significantly ($P<0.05$). During foam formation, proteins adsorb to air-water interface rapidly and reduce the surface tension, so the foam formation improves due to the increase in the viscosity and elasticity [30]. Wierenga et al. (2003) [27] showed that egg albumin, with higher exposed hydrophobicity, reduced the kinetic barrier for its adsorption to the air/water interface. From Figure 2B, we can observe that increasing the BSG concentration had an adverse effect on the foam expansion and led to an increase in foam density. As mentioned earlier, when BSG is added to any liquid, it is expected to increase the viscosity of that liquid. Subsequently, the viscous liquid would prevent the trapping of air during whipping or mechanical mixing, which in turns, results in a reduction of the foam expansion [18]. These findings achieved in the present study are in agreement with the results reported for the foam-mat drying of fruits such as star fruit [21] and bael fruit [17].

Optimization

In the current study, optimization was based on high foamability and foam stability. Indicators and targets for each variable are shown in Table 3. Since stability is one of the most important parameters in foam-based food products, in this experiment, higher stability and lower drainage were used for stability optimization. In the case of foamability, as another important parameter in foam-based products, the optimization was done based on higher overrun and lower density. Optimum conditions on production of the foam were 0.5% (w/v) albumin and 0.3% (w/v) BSG (Figure 3). Stability, overrun, drainage, and density were 0.957, 70.46, 0.083, and 0.527, respectively. High-molecular-weight polysaccharides may not be adsorbed at the air-water interface, but they can improve foam stability as thickening or gelling factors [31]. As mentioned previously, in this experiment, at the higher amounts of BSG, the foam overrun decreased. This can be related to the increase in viscosity of the aqueous phase caused by BSG, which could prevent entering air to the system [31]. Accordingly, 0.3% (w/v) BSG was chosen as the best concentration for preparation of the foam. On the other hand, egg albumin showed a good foamability and foam stability at the higher concentration; 0.5% (w/v) can be suggested as the best concentration.

Parameter	Aim	Minimum	Maximum	Importance
Albumin (g)	In range	0.3	0.5	3
BSG (g)	In range	0.1	0.6	3
Stability (%)	Maximum	0.7	1	3
Overrun (%)	Maximum	6.8	132.7	3
Drainage	Minimum	0	0.61	3
Density (g/cm ³)	Minimum	0.393	0.858	3

Table 3: Indicators and targets for optimization of foam production.

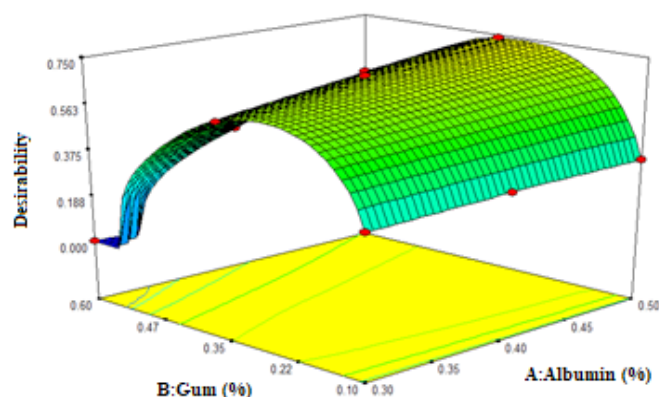


Figure 3: Optimum conditions of foam preparation using basil seed gum (BSG) in combination with egg albumin.

Rheological Properties

Optimum conditions (desirability) of foam preparation using BSG in combination with egg albumin are presented in Figure 3. The amplitude sweep for samples containing 0.3% (w/v) BSG and 0.4% (w/v) albumin is presented in Figure 4A. G' , G'' and $\tan(\delta)$ were used to determine LVE region. The results showed that G' and G'' decreased as strain increased. When strain increased, G' crossed G'' . This point is known as the crossover point, which indicates the structural changes in the sample. After this point, G'' is more than G' ($\tan(\delta) > 1$) that indicates a structure rupture and start of the flow behavior. For most of the solid food, LVE is between 0.1% to 2% [32]. We choose the strain of 0.1% in LVE region.

The results of frequency sweep indicated that G' is greater than G'' at all frequency applied, exhibiting a 'solid-like' behavior (Data not shown). Increasing the frequency, increased G' in the case of all samples, which could be related to the formation of the macromolecular structure at the higher frequency. We previously

observed similar results for the heat-induced BSG-albumin gels [33]. Maximum G' was observed when BSG was added to the albumin solutions at any concentration, perhaps due to the reinforcement of the statement of the interactions between the polysaccharide and the protein, and so the increase in the interfacial rigidity [15]. The increase in G'' with an increase of the frequency can be related to a breakdown of the bondings that do not have time for rebuilding the structure and when the breakdown occurs, viscous modulus increases accordingly. Moreover, there was no crossover point at frequency sweep test, which indicates the solid-like behavior of foams, consistent with the report of [32].

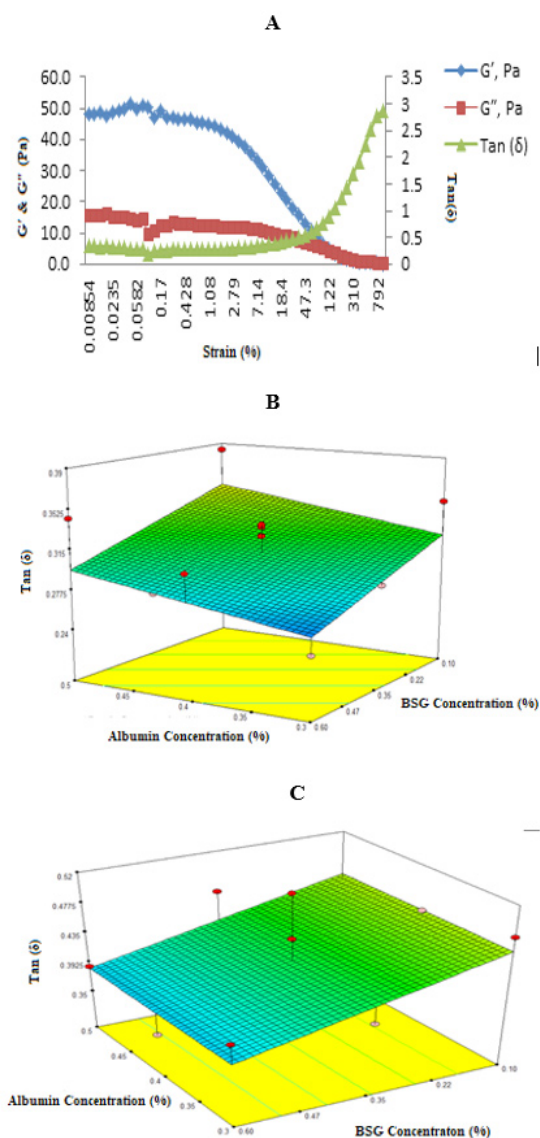


Figure 4: G' , G'' , and $\tan(\delta)$ as strain function for experimented foams containing 0.4% egg albumin and 0.3% basil seed gum (BSG) at amplitude sweep test (A), $\tan(\delta)$ at constant frequency of 1 Hz (B), and 10 Hz (C) at the frequency sweep test.

Rheological properties are associated with the structural properties of the food and can be used to correlate with the foam stability [2]. $\tan \delta$ can be defined as the ratio of the viscous and elastic modulus. When G' is greater than G'' ($\tan \delta < 1$ or $\delta < 45^\circ$), the material may show a solid-like behavior; whereas, when G' is smaller than G'' ($\tan \delta > 1$ or $\delta > 45^\circ$), it may show a fluid-like behavior. According to Figure 3 (B & C), the fresh foam showed a solid-like behavior ($G' > G''$, $\tan \delta < 1$). Rafe and Razavi (2013) and Naji-Tabasi and Razavi (2017) [31,32] also reported a solid-like behavior of BSG at experimental concentrations of 1-3% (w/v) and 1% (w/v), respectively. At a frequency of 1 Hz (Figure 3B), $\tan \delta$ was higher at high concentrations of albumin and low concentrations of BSG. This trend was similar to the frequency of 10 Hz (Figure 3C). Albumin is a protein with high foamability properties, and thus, an increase in albumin concentration was expected to increase the foam overrun. Generally speaking, at the higher amount of overrun, foams contain a high amount of air, which leads to the increase in viscose behavior (increasing $\tan \delta$) [2]. In the case of the current investigation, the addition of BSG decreased the foam overrun, which led to an improvement in the storage modulus (decrease in $\tan \delta$).

Conclusion

In order to improve the foam stability and/or rheological properties of the foam-based food products containing egg albumin, polysaccharides such as BSG can play an important role by different mechanisms. In this research, the effect of BSG, as a stabilizing agent, on foaming properties of egg albumin was investigated, and then the optimum concentrations of both the polysaccharide and the protein were obtained by RSM. The findings demonstrated that the addition of BSG (0.1-0.3%, w/v) significantly ($P < 0.05$) improved the foaming properties of egg albumin. Increasing the albumin concentration from 0.3% to 0.5% (w/v) raised the foam overrun, while it decreased the foam density. Rheological analyses showed that LVE was at a strain of 0.1%. Storage and loss moduli increased as frequency increased, and BSG had a great impact on these moduli. We also observed that an increase in the concentration of BSG, increased the stability and density of albumin foams, but decreased their drainage and overrun. The best quality of the foams was observed at the concentrations of 0.3% and 0.5% (w/v) for BSG and albumin, respectively. The main reasons that polysaccharides such as BSG can act as foam stabilizers, are their high surface activity, their ability to increase the viscosity of the dispersion medium, and their ability to form gel-like charged and thick adsorbed layers. Foaming is one of the most important processing operations during manufacture of the foam-based food products (e.g. whipped cream, ice cream, meringue, soufflés, cakes, mousse, and marshmallow), as foaming has a very substantial effect on the structural and rheological properties of these types of foods. Consequently, it is suggested that BSG, as a novel polysaccharide, can be used in order to increase the foam

stability and improve the foamability of egg albumin in the foam-based food products.

Highlights

- BSG increased the stability and density of the foam made from egg albumin.
- Foam density was lower at higher amounts of egg albumin and lower amounts of BSG.
- Foam stability increased as the concentration of basil seed gum increased.
- Foam overrun was higher at higher amounts of egg albumin and lower amounts of BSG.
- Increase in the concentration of BSG resulted in a significant decrease in $\tan \delta$.

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