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DETERMINATION OF THE FOAMING AND EMULSIFYING PROPERTIES OF LYOPHILIZED WHOLE QUAIL EGG, EGG YOLK AND EGG WHITE

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ABSTRACT
The aim of the study was to investigate the foaming and emulsifying properties of lyophilized whole quail egg, egg yolk and egg white. The microstructural properties of oil-in-water emulsions of egg powders were determined and rheological properties of mayonnaise-like product produced using egg yolk powder were investigated. The highest foaming capacity was recorded for egg white powder at all pH levels. Egg yolk powder at 1% dispersion level had the highest emulsion activity index value ($P<0.05$). Micrographs of scanning electron microscope (SEM) proved that the finest emulsion was prepared using egg yolk powder. Mayonnaise-like product produced using egg yolk powder exhibited gel-like structure (G'>G") with shear thinning behavior. Quail egg yolk powder was successfully used in production of a product having acceptable rheological properties. Consequently, it was shown that lyophilized quail egg powders had potential to be used as alternative foaming and/or emulsifying agents in food products.
Keywords: Quail egg, lyophilization, emulsion, scanning electron microscopy, rheology

LİYOFİLİZE BILDIRCIN YUMURTASI, YUMURTA BEYAZI VE YUMURTA SARISININ KÖPÜK OLUŞTURMA VE EMÜLSİFİKASYON ÖZELLİKLERİNİN BELİRLENMESİ

ÖZ
Bu çalışmanın amacı liyofilize edilmiş bıldırcın yumurtası, yumurta beyazı ve yumurta sarısının köpük oluşturma ve emülsifikasyon özelliklerini araştırmaktır. Liyofilize bıldırcın yumurtası tozlarının suda yağ emülsiyonlarının mikroyapısal özellikleri belirlenmiş, yumurta beyazı tozu kullanılarak üretilen mayonez benzeri ürüne ait reolojik özellikler araştırılmıştır. En yüksek köpük oluşturma kapasitesi, tüm pH değerlerinde yumurta beyazı ile elde edilmiştir. En yüksek emülsiyon aktivite endeksi değeri, %1 dispersiyon düzeyinde yumurta sarısı tozu ile elde edilmiştir ($P<0.05$). Taramalı elektron mikroskobu (SEM) ile elde edilen görüntüler, en iyi emülsiyonun yumurta sarısı tozu ile elde edildiğini kanıtlamıştır. Liyofilize bıldırcın yumurtası sarısı ile üretilen mayonez benzeri ürünün kayma incelmesi davranışı sergilediği ve jel benzeri yapı (G'>G") oluşturduğu belirlenmiştir. Liyofilize bıldırcın yumurtası sarısı, kabul edilebilir reolojik özelliklere sahip mayonez benzeri ürün üretiminde başarılı bir şekilde kullanılmıştır. Sonuç olarak, liyofilize bıldırcın yumurtası tozlarının, gıda ürünlerinde köpük oluşturucu ve/veya emülsiyon oluşturucu alternatif bileşen olarak kullanılabilme potansiyelinin mevcut olduğu gösterilmiştir.
Anahtar kelimeler: Bıldırcın yumurtası, liyofilizasyon, emülsiyon, taramalı elektron mikroskobu, reoloji

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INTRODUCTION

Japanese quail (*Coturnix coturnix japonica*) is a domesticated small bird and commercially used for egg and meat production due to its fast growth and laying rate, rapid sexual maturity, and low feed requirements compared to other raised birds such as chicken, turkey and duck (Panda and Singh 1990; Rahman et al. 2016). The quail products are not accepted as a food source worldwide, but they are becoming more popular as conventional food in Europe and Asia. Having high content of protein with low fat and cholesterol along with the high mineral and vitamin content makes quail egg not only a good source of nutrients but also a potential ingredient for industrial food applications (Segura-Campos et al. 2013). The high protein content of quail egg proves that it can serve as an emulsifier or a binder in various food processing applications (Tokusoglu, 2006; Duraklı Velioglu et al. 2018; Segura-Campos et al. 2013). In the literature, there are studies investigating the functional properties of chicken and quail egg components (Segura-Campos et al, 2013; Öztürk et al. 2016; Orishagbemi et al. 2017) and quail egg was reported to exhibit superior functional properties than chicken egg (Kudre et al., 2018). There are also studies about the effect of processing on the functionality of egg components (Huang et al., 2016), since the processes such as heat treatment, drying, freezing and thawing applied to egg could alter the functional properties such as foaming, gelling and emulsifying by means of structural unfolding of the proteins and also lipoproteins (Thierau et al. 2014). However, the studies about the functionality of quail egg is still limited and to the best of our knowledge, microstructure and rheological properties of oil-in-water emulsions produced using lyophilized quail egg were not studied. Therefore, the aim of the present study was to investigate the foaming and emulsifying properties of lyophilized whole quail egg, egg white and egg yolk. For this aim determination of the aforementioned functional properties along with the microstructural properties of oil-in-water emulsions of lyophilized quail egg powders and rheological properties of mayonnaise-like product produced using egg yolk powder was accomplished. Additionally, proximate composition of the samples was determined.

MATERIALS AND METHODS

Preparation of egg powders

A total of 240 eggs from Japanese quail were obtained from quail coops of Department of Animal Science, Namık Kemal University, Tekirdag, Turkey. All eggs were stored at 4°C until the analysis. Eggs were deshelled manually and egg white, egg yolk and whole egg were obtained in liquid form and collected in polyethylene sample containers. The vitelline membrane was removed at the separation step of the egg yolk. Then, as a pretreatment, all the liquid samples were stored at -80°C in freezer (TSU700, Thermo Fisher Scientific, OH, USA) for 24 h. The samples were lyophilized using a laboratory freeze dryer (Alpha 2-4 LDPlus, Christ GmbH, Germany) at a temperature of -76°C and pressure of 0.001 mbar. The samples were used without defatting. Dried and powdered samples were stored at -20°C for further analysis.

Proximate composition

Total protein, ash, moisture and fat analysis of the samples were done according to the AOAC official methods 954.01, 923.03, 925.09 and 920.39, respectively (Horwitz, 1997).

Water and fat absorption capacities

Both water absorption capacity (WAC) and fat absorption capacity (FAC) analyses were done according to the methods described by Segura-Campos (2013) and Lili et al. (2015) with slight modifications. One gram (W) sample and 10 ml distilled water or corn oil were mixed in pre-weighed 15 ml centrifuge tube using a vortex for 1 min at room temperature. Sample was left to stand for 30 min at 30°C in an incubator. The initial volume of the mixture (V_1) was recorded. Tubes were centrifuged at a speed of 2500 g for 20 min. The supernatant volume (V_2) was recorded. Equation 1 was used for calculation of water and fat absorption capacities. The results were given as ml of water per gram of sample and ml of oil per gram of sample for water and fat absorption capacity, respectively.

$$WAC/FAC = \frac{V_1 - V_2}{W} \quad (1)$$

Emulsifying properties

The method described by Kudre et al. (2018) was used for determination of emulsion activity index (EAI) and emulsion stability index (ESI) of samples with slight modifications. Corn oil (6 ml) and egg powder suspensions (1%, 2% and 3%, 18 ml) were homogenized with homogenizer (T25 Ultra-Turrax, IKA-Werke GmbH, Staufen, Germany) at 10000 rpm for 2 min. One ml emulsion was diluted with 99 ml 0.1% SDS solution. After mixing with vortex for 20 s, initial absorbance of the mixture (A_0) and the absorbance at 10th min (A_{10}) were read at 500 nm using a spectrophotometer (Optizen POP UV-Vis, Mecasys Co. Ltd., Daejeon, Korea). Equation 2 and 3 were used for calculation of EAI and ESI:

$$EAI\ (m^2/g) = \frac{(2 \times 2.303 \times A \times DF)}{(l \times \emptyset \times C)} \quad (2)$$

$$ESI\ (min) = \frac{A_0}{(A_0 - A_{10})} \times \Delta t \quad (3)$$

where DF is the dilution factor of the emulsion (100), l is the path length of spectrophotometer cuvette (m), Φ is the oil volume fraction, C is the protein concentration in aqueous phase (g/m^3) and Δt is 10 min.

Foaming properties

Foaming capacity (FC) and foam stability (FS) were investigated according to the methods described by Segura-Campos et al. (2013) and Kudre et al. (2018) with slight modifications. A 50 ml solution prepared with 3% sample and distilled water was blended at 5000 rpm for 5 min using homogenizer. The pH value of the solution was adjusted to 2, 3, 4, 4.5, 5, 6, 7, 8, 9, 10, 11 and 12 and the analysis was repeated for every single pH value. FC was calculated using the foam volume at the 30th second. FS values were calculated using the foam volumes recorded at the 30th and 60th min after homogenization. Equation 4 and 5 were used for calculation:

$$FC(\%) = \left(V_f/V_0\right) \times 100 \quad (4)$$

$$FS(\%) = (V_t/V_0) \times 100 \quad (5)$$

where, V_f is the final volume of the foam at the 30th second after homogenization, V_0 is the volume of protein dispersion at the beginning of the analysis (50 ml) and V_t is the volume of the foam recorded at the 30th and 60th min after homogenization.

Color analysis

Color measurements (*L**, *a**, *b** values) of the powdered samples and the emulsions were performed using a colorimeter (Chroma meter CR-5, Konica Minolta, Japan). The sample was filled in a Petri dish avoiding any gap. Three replicate measurements were performed and the average of the results was used. In the *Lab* color space, *L**, *a** and *b** values indicate the lightness, red/green and yellow/blue coordinates, respectively.

Microscopic analysis of emulsions

Emulsions of egg yolk, egg white and whole egg powders with corn oil were prepared. Total emulsion was composed of 1.3% egg powder, 23.7% distilled water and 75% corn oil for every single emulsion. Powdered sample was rehydrated using distilled water and during homogenization process at 7000 rpm with homogenizer, corn oil was added at a speed of 0.2 ml/sec. Fine emulsions were stored at +4°C until microscopic analysis. Micrographs of the emulsions were obtained using scanning electron microscopy (FEI-SEM QUANTA FEG 250, Thermo Fisher Scientific, Oregon, USA). Environmental Scanning Electron Microscopy (ESEM™) mode with gaseous secondary electron detector (GSED) was used in order to avoid breakage of emulsion. Emulsions were cooled down to 5°C on peltier cooling stage and the images were captured at this temperature. The chamber had a pressure of 100-150 Pa and the micrographs with maximum resolution were saved.

Rheological measurements of the mayonnaise-like products

The quail egg yolk powder was utilized in the production of mayonnaise-like product. Fresh egg yolk was used in order to produce a control sample. The mayonnaise-like products were prepared according to the formulation of Huang et al. (2016) with slight modifications. 0.67 g salt, 1.3 g sugar, 5 g egg yolk powder and 10 ml water was mixed at low speed (3000 rpm) for 1 min., and then the oil was added drop-wise during the blending at high speed (10000 rpm) using homogenizer. Vinegar was added at the last step and blended again for 1 min. The mayonnaise-like products produced using egg yolk powder and fresh quail egg yolk were coded as A and B, respectively. The rheological properties of the mayonnaise-like products were determined using Discovery Hybrid Rheometer-2 (TA Instruments, DE, USA). 40 mm standard peltier parallel-plate configuration was used as the geometry. The measurements were conducted at a 1100 μm gap distance at 25 °C. Flow curves were obtained at a controlled shear rate which increased linearly in the 0.1-100 1/s shear range, then decreased linearly to 0 1/s in a total duration of 100 s (Huang et al. 2016). Herschel-Bulkley rheological model was used to determine the flow behavior characteristics as shown in Equation 6:

$$\tau = \tau_0 + k \cdot \gamma^n \quad (6)$$

where, τ, τ_0, k, γ and n represent shear stress (Pa), yield stress (Pa), consistency index (Pa.s^n), shear rate (s^{-1}) and flow index, respectively (Stokes and Telford 2004). Herschel-Bulkley model parameters and R^2 values were determined by the TA instrument software (TA Instruments, DE, USA).

Oscillation tests were performed for the measurement of structure without deformation (Kurt and Genccelep 2018). Firstly, the linear viscoelastic range was determined using strain sweep (0.001-100%) at a frequency of 1.0 Hz. Within the linear viscoelastic range, the frequency sweep test was performed within a frequency range of 0 and 400 rad/s at 25°C. The storage modulus (G') and loss modulus (G'') values were recorded and plotted as a function of angular frequency. Temperature sweep test was conducted by using a constant strain of 0.1% within the linear viscoelastic range at a frequency of 10 rad/s. The test was performed over a temperature range between 30 to 80°C with increments of 2°C/min. The storage modulus (G') and loss modulus (G'') values were recorded and plotted as a function of temperature.

Statistical analysis

All analyses were done in duplicate. The data obtained from the analysis were subjected to ANOVA and Duncan multiple test was used to show differences between the mean values using the software PASW Statistics 18.0.0 (IBM, New York City, New York, USA).

RESULTS AND DISCUSSION

Proximate composition

The proximate composition of lyophilized egg yolk, egg white and whole egg is reported in Table 1. As expected, the highest protein content was found in egg white powder as 92.8% and this finding was compatible with the findings reported by Segura-Campos et al. (2013) and Kudre et al. (2018) for dried egg white. The protein content of whole egg powder was found as 41.0% which was lower than the finding reported for whole quail egg (50.8%) by Tokusoglu (2006). The lipid content of egg white powder (0.7%) found in this study was in general agreement with the values present in literature. The egg yolk and whole egg powders used in the present study included 52% and 39% lipids, because in the present study these powders were not subjected to additional defatting step. However, in their study, Kudre et al (2018) defatted the egg yolk and whole egg samples using hexane after the lyophilization step. The other slight differences in proximate composition may be due to the different feeding practices and welfare conditions of the birds used as material in different researches.

Water and fat absorption capacities of egg powders

Egg white powder showed significantly high water absorption capacity (7.21 ml/g) compared with yolk (2.84 ml/g) and whole egg powder (4.50 ml/g) (P<0.05). The result could be explained by the previous finding of this study as the more the protein content in egg white powder, the higher the water absorption ability of the sample. Additionally, the high water absorption capacity can be related with the exposure of polar groups in egg white protein which have significant effect on the amount of absorbed water (Lili et al. 2015). The samples of the present study showed better water absorption capability than that of reported by Segura-Campos et al. (2013). The reason of this difference may be the dehydration technique they used over 65°C which caused more damage on egg proteins in the meaning of water absorption ability. On the other hand, there was no significant difference between oil absorption capacities of the powdered samples which were measured as 2.21, 2.70 and 2.22 ml/g for egg yolk, egg white and whole egg powder, respectively (P>0.05).

Table 1. Proximate composition of lyophilized quail egg white, egg yolk and whole egg and color values of these powdered samples and emulsions prepared using these samples

Sample	*L**	*a**	*b**	Protein [%, w/w]	Lipid [%, w/w]	Moisture [%, w/w]	Ash [%, w/w]
Sample in powder form							
Egg white	91.67±0.26^{a}	-1.50±0.08^{c}	16.90±0.22^{c}	92.8±0.4^{a}	0.7±0.0^{c}	2.8±0.1^{a}	3.1±0.1^{c}
Egg yolk	87.30±0.19^{b}	9.35±0.17^{b}	34.62±0.33^{a}	37.9±6.4^{b}	52.0±2.0^{a}	1.0±0.0^{c}	5.1±0.3^{a}
Whole egg	79.95±0.33^{c}	12.88±0.14^{a}	32.33±0.33^{b}	41.0±2.7^{b}	39.0±3.2^{b}	2.0±0.1^{b}	4.2±0.0^{b}
Emulsions							
Egg white	80.73±0.24^{c}	-1.86±0.02^{c}	14.14±0.12^{c}				
Egg yolk	88.96±0.16^{a}	-0.14±0.00^{b}	15.10±0.02^{b}	-	-	-	-
Whole egg	84.52±0.02^{b}	0.26±0.00^{a}	15.86±0.02^{a}				

The results are given as mean values ± standard errors (SE). Different letters in the column indicate significant differences (P<0.05).

Emulsifying properties

Different proteins and protein sources have been investigated for their functional properties and behaviors in model foods and emulsions, and the functionality of proteins is mostly evaluated in oil-in-water emulsions (Mao and Hua 2012; Kurt and Genccelep 2018). In these type emulsions, the coating of oil droplets and minimal remaining in the dispersed phase are the indicator properties of successful emulsifiers (Foegeding 2015).

Fig. 1a presents the EAI and ESI values of the quail egg powder samples at different dispersion levels (1, 2 and 3%). It can be seen from the figure that the EAI values differ with the dispersion levels used. The results showed that at 1% dispersion level, egg yolk powder had the highest EAI value (P<0.05). At 2% dispersion level, there were no significant difference between EAI values of egg yolk and whole egg powders (P>0.05). The EAI of egg yolk and egg white powders decreased as the level increased from 1% to 3%. On the contrary, EAI value of whole egg powder increased with an increase in powder level in emulsion. It is reported that at low protein concentrations, protein migration takes place in a diffusion controlled manner, and this enables the proteins to unfold and localize at the oil-water interface in the emulsions. Conversely, at high protein concentrations, the proteins accumulate in aqueous phase causing a decrease in EAI. This is explained by the activation energy barrier at higher protein concentrations which blocks the protein migration to take place in diffusion controlled manner (Kudre et al. 2018). The result of the present study for EAI of egg white powder at 1% level (24.04 m^2g^{-1}) was compatible with the finding of Kudre et al. (2018) which was reported as 22.51 m^2g^{-1} for lyophilized quail egg white sample. However, the EAI values for egg yolk (26.30 m^2g^{-1}) and whole egg (20.49 m^2g^{-1}) samples of the present study were lower than their findings which were reported as 33.03 m^2g^{-1} and 26.64 m^2g^{-1} for egg yolk and whole egg powders, respectively

(Kudre et al. 2018). These differences in egg yolk and whole egg powder samples may be because of the additional defatting step they used. Using the defatting step, they obtained products having higher protein content affecting the emulsifying properties. Moreover, the structural unfolding of lipoproteins as well as proteins in the egg yolk samples used in the present study may cause the differences in emulsifying properties of the samples. Also the freezing and thawing conditions could affect the emulsifying properties (Huang et al., 2016). In addition, EAI is a function of oil volume, amount of protein and the procedure and equipment used in emulsion production, hence the differences between the results found in literature are explicable (Pearce and Kinsella 1978).

(a)

(b)

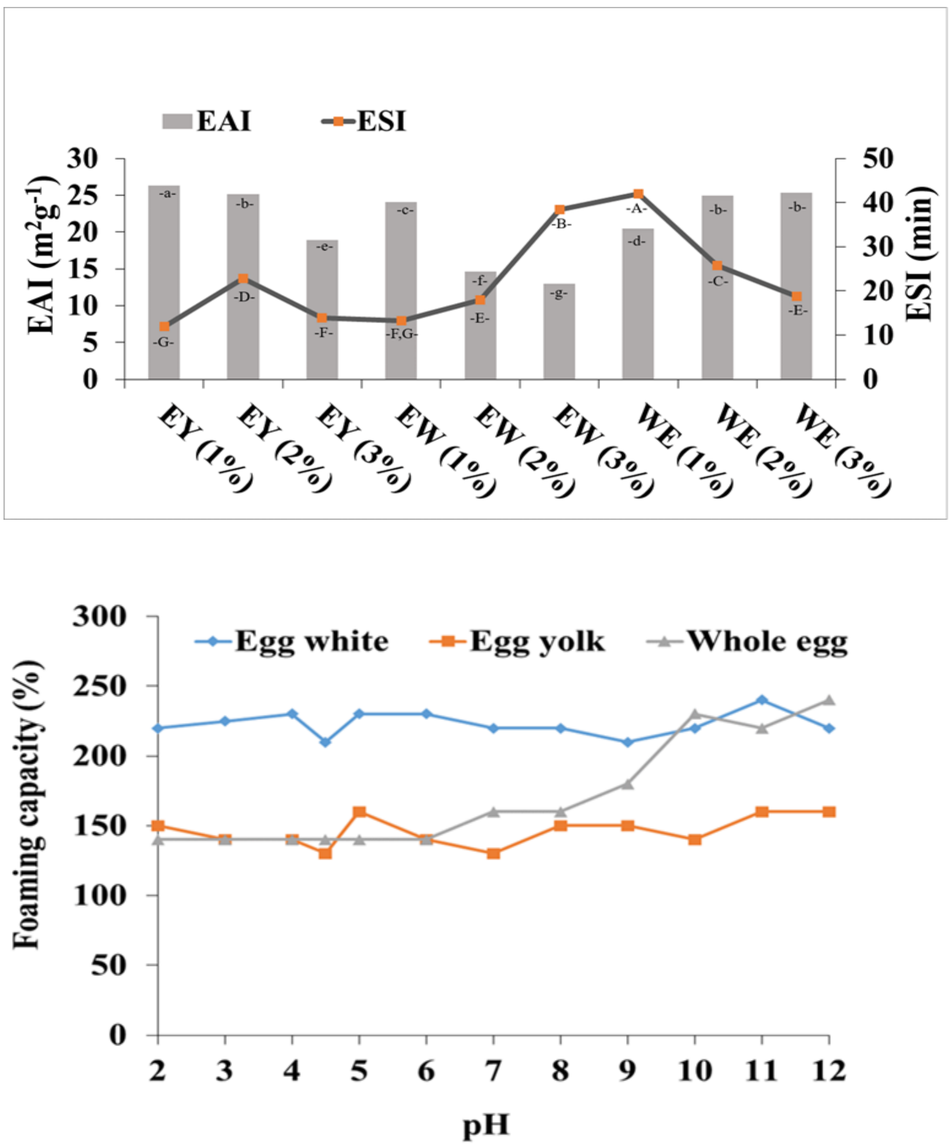


Fig 1(a) Emulsifying properties of the lyophilized egg yolk (EY), egg white (EW) and whole egg (WE) samples: Emulsion activity index (EAI) and emulsion stability index (ESI) values (*Different lowercase letters indicate the significant differences in EAI values. Different uppercase letters indicate the significant differences in ESI values* (P<0.05). (b) Foaming properties at different pH levels

As known, an emulsion is not stable evermore and, oil and water phases show affinity for separation. That is why the results for ESI value is time depending. In the present study, 10 min time interval was used for ESI measurement and the results are given in Fig. 1a. The ESI values reported by Lili et al. (2015) and Kudre et al. (2018) were higher than the results of the present study. However, it was found that ESI increased with the increase in dispersion level for egg white powder as also reported by Kudre et al. (2018). The same tendency was not observed for egg yolk and whole egg powders. The ESI value decreased slightly at 3% level of egg yolk powder. The ESI values for whole egg powder also decreased with the increase in dispersion level, and these can be because of the differences in the protein content of the products used in this study. Kudre et al. (2018) reported partial protein denaturation through drying as a factor which had a positive effect on the emulsifying properties by means of increasing the molecular flexibility and superficial hydrophobicity. The differences in the process conditions used and the differences in the composition could be effective on the emulsifying properties of the samples.

Foaming capacity and foam stability

Foaming properties were investigated at different pH values for all samples. Foaming ability of the egg proteins depends on their localization at the air-water interface and homogenous distribution in the dispersion. While the solubility of egg powders is a pH dependent manner due to the isoelectric point of individual proteins existing in the sample, it is expected that the solubility is the lowest or not at or near the isoelectric point (Lili et al. 2015). As expected, the highest foaming capacity was recorded for egg white powder as shown in Fig. 1b. There are several proteins in egg with different isoelectric points. The major protein in egg white is ovalbumin and it has low solubility at its isoelectric point, pH 4.5. The decrease in FC at pH 4.5 could be explained by the isoelectric point of ovalbumin. While the results of the present study were compatible with the results expressed by Kudre et al. (2018), sharp decreases were not recognized in foaming capacity with the increase in pH levels as reported by Segura-Campos et al. (2013). FC values measured in the present study verified that foam formation occurs in an isoelectric point dependent manner and decreases at pH 4.5 and 9.0 which are the isoelectric points of ovalbumin and lysozyme, respectively (Rao et al. 2013).

Foam stability values for egg white, egg yolk and whole egg powders at 30 and 60th min and different pH levels are seen in Fig 2. The FS values of egg white powder were generally higher than that of egg yolk and whole egg. The highest FS value was measured as 200% at pH 11. Hoppe (2010) reported that ovomucin, one of the major proteins in egg white, has long carbohydrate chains which may increase the foam stability with high water retention ability. In the same study, it was found that the foam stability at pH 9.11 was higher than that of pH 6. On the contrary, Segura-Campos (2013) reported a decrease in FS value with the increase of pH. The results of the present study for FS were significantly higher than the results found by Lili et al. (2015). In their study, FS values for egg white protein produced by both spray drying and freeze drying methods were approximately 30%. The difference between the findings could be explained by the denaturation effect of spray drying on egg proteins and/or the measurement of FS value.

Color values of the samples

The color parameters (L^*, a^*, b^*) of powdered samples and emulsions are given in Table 1. As expected, L^* value of egg white powder was the highest such as the b^* value of egg yolk powder. The differences were significant for every color parameter in sole sample group ($P<0.05$). L^* value of the emulsion containing egg yolk powder was higher than that of other samples. This was probably because of the high fat content of the egg yolk. It was reported that higher fat content and smaller fat droplets in the emulsion result in high L^* values because of the good refraction of light (Thaiudom and Khantarat 2011).

Microscopic structure of emulsions

The most critical point in microscopic analysis of emulsion is the use of cooling stage at 5°C that avoids the coalescing of oil droplets. SEM micrographs showed that the emulsification ability of egg yolk (Fig. 3a) was better than whole egg (Fig. 3b) and egg white (Fig. 3c). As reported by Buxmann et al. (2010), if the role of every single egg yolk component is considered separately, egg yolk proteins determine the emulsifying activity. As can be seen from Fig 3a, the distribution of oil droplets in the emulsion prepared with egg yolk powder was homogenous and there was a smooth structure. On the other hand, the emulsion prepared with egg white powder had many oversized and deformed oil droplets which were expected to be unstable in shelf life of such an emulsion. There was a moderate surrounding effect of proteins in the emulsion prepared with whole egg powder and this finding proved that the whole egg powder could also be preferred in the preparation of an emulsion.

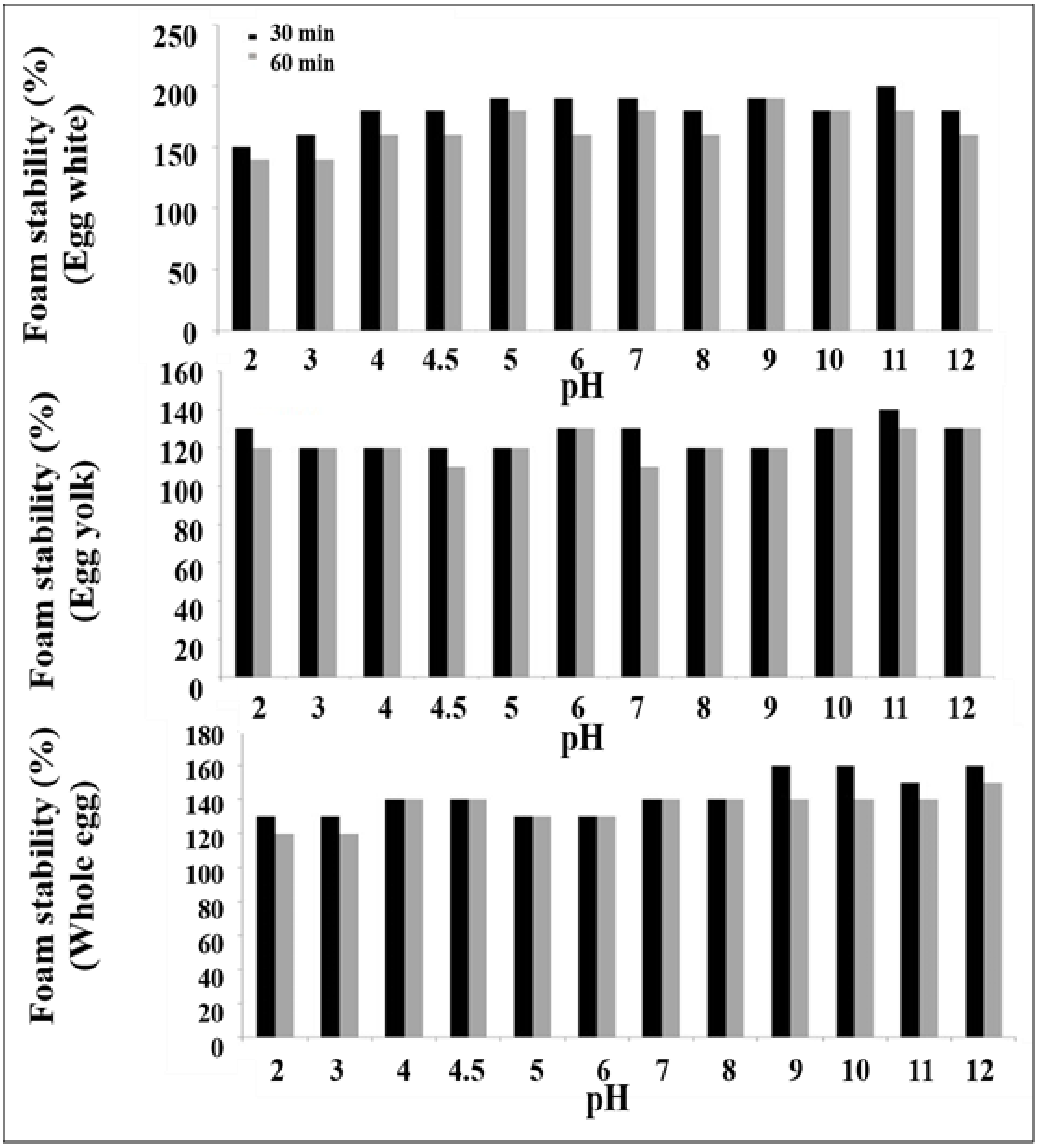


Fig 2 Foam stability of lyophilized egg yolk, egg white, and whole egg samples

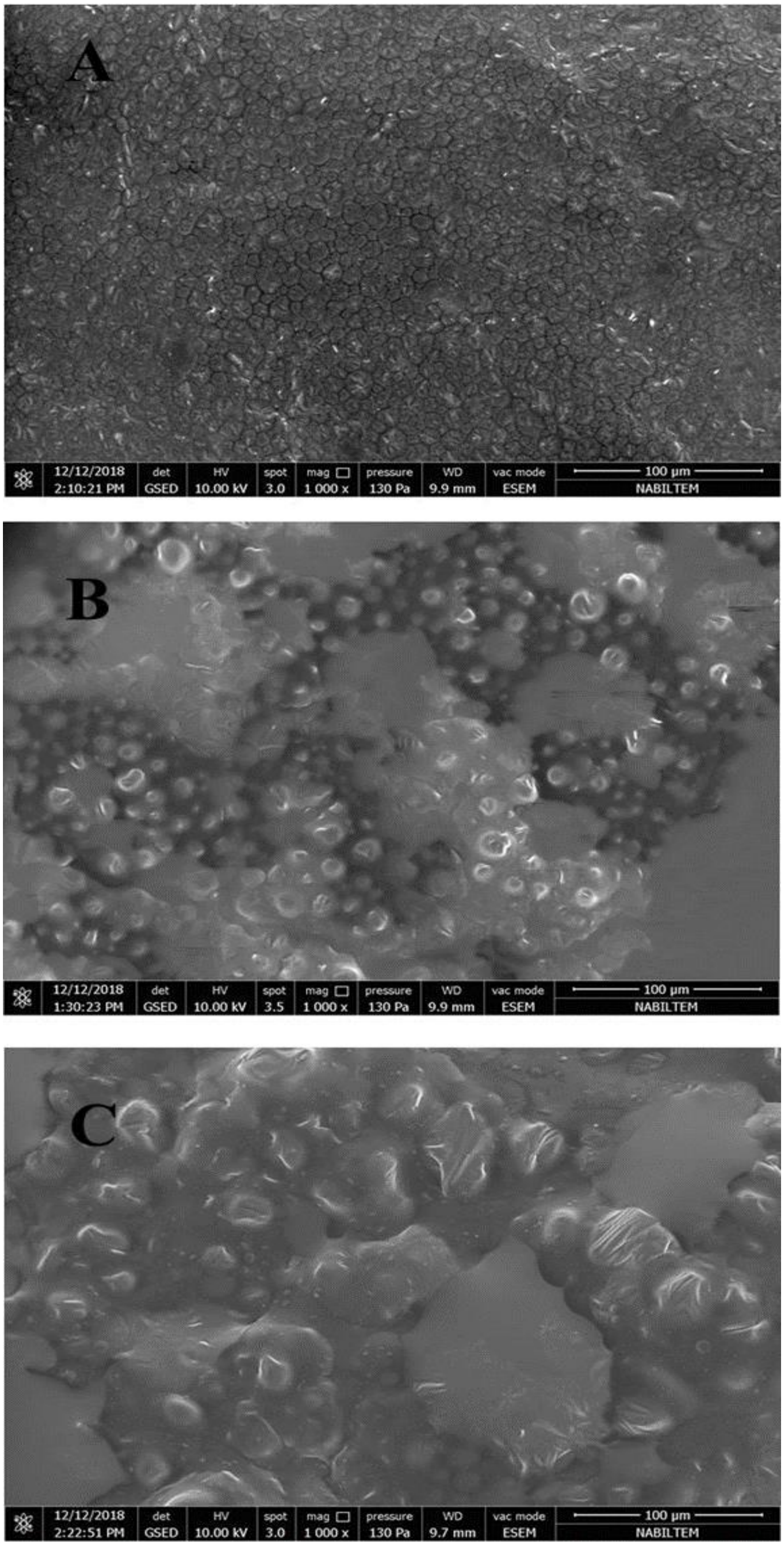
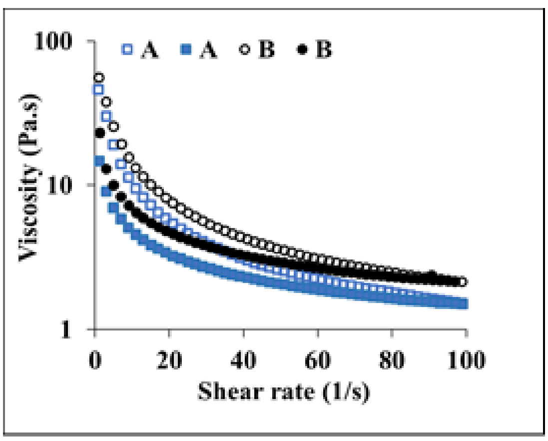


Fig 3 Micrographs of the emulsions prepared with egg yolk (a), whole egg (b) and egg white (c) powder

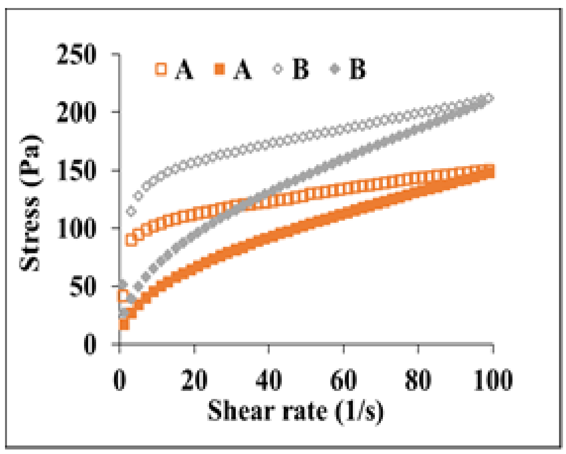
Rheological properties of the mayonnaise-like products produced using egg yolk powder

Typical flow curves for mayonnaise-like samples were obtained as seen in Fig. 4a and 4b. The experimental data fitted the Herschel-Bulkley model well having high R^2 values (0.998 for sample A and 0.995 for sample B). For Sample A and B, n values were 0.57 and 0.52, respectively. When the consistency index values (4.76 and 8.71 Pa.s^n for A and B) were compared, control sample could be seen as the emulsion with higher viscosity. The change of viscosity of the mayonnaise samples with the increase in shear rate is seen in Fig. 4a. The higher the shear rate, the lower the viscosity value indicating a non-Newtonian flow behavior. As expected, flow behavior of products like mayonnaise display shear-thinning response, probably because of the breaking up of oil droplet clusters with applied shear (Liu et al. 2018).

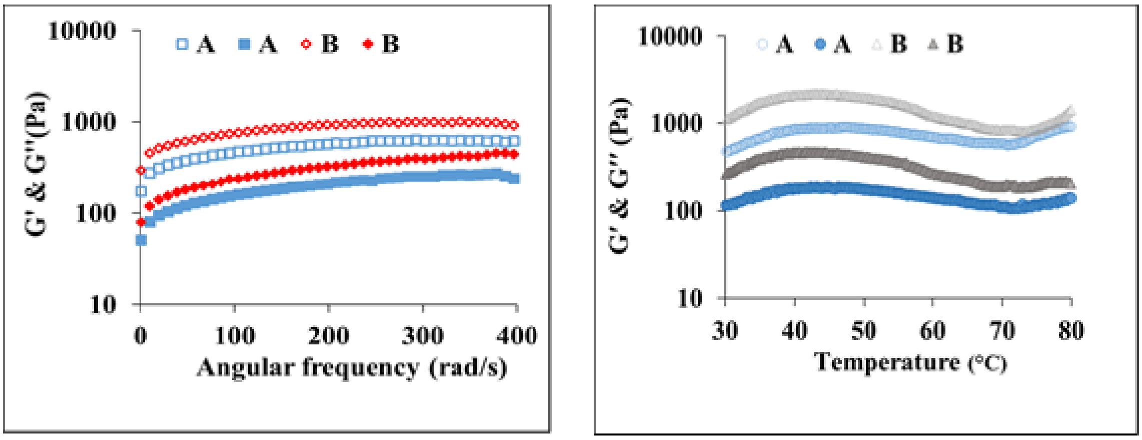
In case of emulsions like mayonnaise, there is a critical level of stress that must be reached to flow. This value is called as yield stress and is of great importance in processing and stability of the product (Stokes and Telfor, 2004). It is also a useful parameter for the prediction of sensory values of products like mayonnaise (Stern et al. 2001). Yield stress values for the upward flow curves were 85.22 and 113.39 Pa for sample A and B, respectively. The yield stress value of sample A was lower than that of control sample (B) showing that the control sample could stand more stress than sample A. This is probably because of the freeze drying process of the egg yolk. Freezing and thawing processes were reported to be effective on the emulsifying properties of egg yolk by Huang et al. (2016). In the literature, there is no study about the rheological properties of the emulsions of the quail eggs. Nevertheless, the yield point of 85.22 Pa is comparable with the values reported in the literature for mayonnaise-like products produced using frozen chicken egg yolk (15-32.4 Pa) (Huang et al. 2016), fresh chicken egg yolk (42.2- 62.9 Pa) and lyophilized chicken egg yolk granules (45.4 Pa) (Laca et al. 2010a). Stern et al. (2001) also reported yield stress values of 43-190 Pa and 94-116 Pa for traditional and light mayonnaise samples containing 2% egg yolk.



(a)



(b)



(c) (d)

Fig 4 Change of viscosity (a) and stress (b) values of the mayonnaise-like samples with shear rate *(Empty symbols and the full symbols represent the upward and downward curve values)*, Change of Storage (G'), and Loss (G'') modulus of the mayonnaise-like samples with frequency (c) and temperature (d) (*Empty symbols represent storage modulus (G') and full symbols represent loss modulus (G'') values. A: mayonnaise-like sample produced using freeze-dried quail egg yolk. B: mayonnaise-like sample produced using fresh quail egg yolk*)

Within the linear viscoelastic range, the strain value of 0.1% was selected to be used in frequency sweep test. According to the results of the frequency tests (Fig. 4c) both of the samples showed a viscoelastic behavior. G' always was higher than G'' throughout the frequency range studied. Fig. 4c also shows the frequency dependency of G' and G'' values. Hence, the mayonnaise-like products produced using quail egg yolk samples showed gel-like behavior (Thaiudoma and Khantara, 2011). Such behavior was also reported for mayonnaise samples studied in the literature (Laca et al, 2010a). It is known that G' of an emulsion is a good indicator of the emulsion's solid-like character originating from the network structure of the emulsion. Hence, it can be concluded that the viscoelastic property of sample A is lower than that of control sample indicating a less solid-like mayonnaise sample showing a weaker structure which can be easily broken under shear stress (Huang et al. 2016). This difference could be attributed to the effect of freezing conditions. The lyophilization process of the quail egg yolk used in the production of the mayonnaise-like product could be effective on the viscoelastic behavior of the product.

The temperature dependence of G' and G'' values of the mayonnaise-like products produced using quail egg yolks were presented in Fig. 4d. All the values started to decrease around 40°C until around 70°C, and then increased. It is obvious that at high temperatures the denaturation of egg yolk proteins occurred. G' value of sample A started to increase after 70°C, and that of the sample B started to increase after 73°C. This point was reported to be the indication of the transition from a liquid-like state to a solid-like state (Laca et al. 2010b). Huang et al. (2016), reported this point between 57.5 - 67°C for the mayonnaise-like products produced using stored frozen chicken egg yolks. The difference could be because of the different raw materials and process conditions used.

CONCLUSION

Foaming and emulsifying properties of lyophilized whole quail egg, egg white and egg yolk were investigated in this study. Lyophilized quail egg white, egg yolk and whole egg had different properties in the meaning of emulsification, foaming and water binding. The highest protein content was found in egg white powder and this resulted to the highest water absorption ability. While the egg white powder was superior in foaming capacity, egg yolk and whole egg powder was good in emulsion formation. SEM analysis of the emulsions prepared with the samples showed that the microscopic structure of the emulsion produced using egg yolk powder was the most homogenous one. Quail egg yolk powder was successfully used in the production of mayonnaise-like product having acceptable rheological properties. As a result, quail egg powders obtained by lyophilization technique could serve as alternative components in food industry. Further research could be conducted about the usage of lyophilized quail egg powders in different food products.

REFERENCES

Buxmann, W., Bindrich, U., Strijowski, U., Heinz, V., Knorr, D., Franke, K. (2010). Influencing emulsifying properties of egg yolk by enzymatic modification with phospholipase D. Part 2: Structural changes of egg yolk due to incubation. *Coll Surf B Biointerfaces* 76: 192-198, doi: 10.1016/j.colsurfb.2009.10.035.

Duraklı Velioglu, S., Baytur, S., Özdinç, N. (2018). Emulsion capacity of lyophilized quail eggs. The 4th Symposium on "Traditional Foods from Adriatic to Caucasus", 19-21 April, Kyrenia, Northern Cyprus, 360 p.

Foegeding, E.A. (2015). Food protein functionality-A new model. *J Food Sci* 80: C2670-C2677, doi: 10.1111/1750-3841.13116.

Hoppe, A. (2010). Examination of egg white proteins and effects of high pressure on select physical and functional properties. MSc thesis, University of Nebraska, the USA.

Horwitz, W. (1997). Official methods of analysis, 17th Ed., Association of Official Analytical Chemists, Washington DC, USA

Huang, L., Wang, T., Han, Z., Meng, Y., Lu, X. (2016). Effect of egg yolk freezing on properties of mayonnaise. *Food Hydrocoll* 56: 311-317, doi: 10.1016/j.foodhyd.2015.12.027.

Kudre, T.G., Bejjanki, S.K., Kanwate, B.W., Sakhare, P.Z. (2018). Comparative study on physicochemical and functional properties of egg powders from Japanese quail and white Leghorn chicken. *Int J Food Prop* 21: 956-971, doi: 10.1080/10942912.2018.1466320.

Kurt, A., Genccelep, H. (2018). Enrichment of meat emulsion with mushroom (*Agaricus bisporus*) powder: Impact on rheological and structural characteristics. *J Food Eng* 237: 128-136, doi: 10.1016/j.jfoodeng.2018.05.028.

Laca, A., Saenz, M.C., Paredes, B., Diaz, M. (2010a). Rheological properties, stability and sensory evaluation of low-cholesterol mayonnaises prepared using egg yolk granules as emulsifying agent. *J Food Eng* 97: 243-252, doi:10.1016/j.jfoodeng.2009.10.017.

Laca, A., Paredes, B., Diaz, M. (2010b). A method of egg yolk fractionation. Characterization of fractions. *Food Hydrocoll* 24: 434-443, doi:10.1016/j.foodhyd.2009.11.010.

Lili, L., Huan, W., Guangyue, R., Xu, D., Dan, L., Guangjun, Y. (2015). Effects of freeze-drying and spray drying processes on functional properties of phosphorylation of egg white protein. *Int J Agric Biol Eng* 8: 116-123.

Liu, X., Guo, J., Wan, Z.L., Liu, Y.Y., Ruan, Q.J., Yang, X.Q. (2018). Wheat gluten-stabilized high internal phase emulsions as mayonnaise replacers. *Food Hydrocoll* 77: 168-175, doi:10.1016/ j.foodhyd.2017.09.032.

Mao, X., Hua, Y. (2012). Composition, structure and functional properties of protein concentrates and isolates produced from walnut (*Juglans regia* L.). *Int J Mol Sci* 13: 1561-1581, doi: 10.3390/ijms13021561.

Orishagbemi, C.O., Ichado, I.B., Sanda, M.E. (2017). Physical, functional and sensory properties of foam mat dehydrated whole egg powder. *J Sci Res Rep* 15: 1-7, doi: 10.9734/JSRR/2017/33305.

Öztürk, B., Urgu, M., Serdaroglu, M. (2017). Egg white powder-stabilised multiple (water-in-olive oil-in-water) emulsions as beef fat replacers in model system meat emulsions. *Sci Food Agric* 97: 2075-2083, doi: 10.1002/jsfa.8012.

Panda, B., Singh, R.P. (1990). Developments in processing quail meat and eggs. *World Poultry Sci J* 46: 219-234, doi: 10.1079/WPS19900022.

Pearce, K.N., Kinsella, J.E. (1978). Emulsifying properties of proteins: evaluation of a turbidimetric technique. *J Agr Food Chem 26*: 716–728, doi: 10.1021/jf60217a041.

Rahman, A.N.A., Hoque, N., Talukder, A.K., Das, Z.C. (2016). A survey of Japanese quail (*Coturnix coturnix japonica*) farming in selected areas of Bangladesh. *Vet World* 9: 940-947, doi: 10.14202/vetworld.2016.940-947.

Rao, Q., Kamdar, A.K., Labuz, T.P. (2013). Storage stability of food protein hydrolysates-A review. *Crc Rev Food Sci* 56: 1169-1192, doi: 10.1080/10408398.2012.758085.

Segura-Campos, M., Perez-Hernandez, R., Chel-Gurerero, L., Castellanos-Ruelas, A., Gallegos-Thintore, S., Betancur-Ancona, D. (2013). Physicochemical and functional properties of dehydrated Japanese quail (*Coturnix japonica*) egg white. *Food Nutr Sci* 4: 289-298, doi: 10.4236/fns.2013.43039.

Stern, P., Valentova, H., Pokorny, J. (2001). Rheological properties and sensory texture of mayonnaise. *Eur J Lipid Sci Technol* 103: 23-28.

Stokes, J.R., Telford, J.H. (2004). Measuring the yield behavior of structured fluids. *J Non-Newtonian Fluid Mech* 124: 137-146, doi:10.1016/j.jnnfm.2004.09.001.

Thaiudom, S., Khantarat, K. (2011). Stability and rheological properties of fat-reduced mayonnaises by using sodium octenyl succinate starch as fat replacer. 11th International Congress on Engineering and Food, Quebec City, Canada. 315-321.

Thierau, S. R., Keil, H., Seuss-Baum, I., Hensel, O. (2014). Effects of Heat Treatment and Freeze-Drying on the Protein and Lipoprotein Structures of Egg Yolk as Determined Using Differential Scanning Calorimetry (DSC). *Agric Commun*, 2(3): 27-37.

Tokuşoğlu, Ö. (2006). The quality properties and saturated and unstaturated fatty acid profiles of quail egg: the alterations of fatty acids with process effects. *Int J Food Sci Nutr, 7-8*: 537–545, doi: 10.1080/09637480601049725.