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CHARACTERIZATION OF THE FOAM-MAT DRIED EGG WHITE POWDER

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ABSTRACT

The scope of this study is to determine the effect of different drying air temperatures on the drying behavior, effective moisture diffusivity, physical, powder, and functional properties of foam mat dried egg white powder. For this purpose, the egg white foam was obtained by using kitchen blender (1000W, 30s) and dried at convective hot air oven at three different drying air temperatures (60, 70, and 80°C, %20 ventilation rate). Drying took place in a falling rate period for all drying temperatures. The effective moisture diffusivity values increased depending on the drying air temperature and the activation energy was calculated as 13.81kJ/mol. The moisture content has a proportional relationship with ash content, b*, Chroma, yellowness and browning indexes, flowability, cohesiveness, emulsification stability, water holding capacity, and foam holding capacity values, whereas it has an inverse proportional relationship with L*, a*, hygroscopicity, emulsification activity, oil holding capacity, and foam holding stability values.

Keywords: Egg white, foam mat drying, powder properties, functional properties, foaming.

KÖPÜK KURUTMA YÖNTEMİ İLE KURUTULMUŞ YUMURTA BEYAZI TOZLARININ KARAKTERİZASYONU

ÖZ

Bu çalışmanın amacı, farklı hava sıcaklıklarının köpük kurutma yöntemi ile kurutulmuş yumurta beyazı köpüğünün kuruma davranışı, etkin nem difüzyon katsayısı, fiziksel, toz ürün ve fonksiyonel özellikleri üzerine etkisinin belirlenmesidir. Bu amaç doğrultusunda, yumurta beyazı köpüğü blender kullanılarak (1000W, 30s) elde edilmiş ve konvektif fırında üç farklı sıcaklıkta (60, 70, ve 80°C, %20 fan hızı) kurutulmuştur. Tüm hava sıcaklıklarında, kuruma düşen hız periyodunda gerçekleşmiştir. Etkin nem difüzyon katsayısı hava sıcaklığına bağlı olarak artmış ve aktivasyon enerjisi 13.81kJ/mol olarak hesaplanmıştır. Nem içeriği; kül içeriği, b*, kroma, sarılık ve esmerleşme indeksleri, akabilirlik, yapışkanlık, emülsiyon stabilitesi, su tutma kapasitesi ve köpük tutma kapasitesi değerleri ile doğru, L*, a*, higroskopisite, emülsiyon aktivitesi, yağ tutma kapasitesi ve köpük tutma stabilitesi ile ters oranlı bulunmuştur.

Anahtar kelimeler: Yumurta beyazı, köpük kurutma, toz özellikler, fonksiyonel özellikler, köpüklenme

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INTRODUCTION

Whole egg and egg-derived proteins are generally used in dressings, baking, and confectionery products due to their functional properties such as foaming, emulsifying, gelling agents, etc. (Ayadi et al., 2008). An egg can be divided into two parts including the egg white (approximately 67% of an egg's liquid weight) and egg yolk. Egg white (egg albumen) consists of about 87.8% water, 9.7 to 10.6% protein, and 0.5 to 0.6 % carbohydrate. In addition, egg white contains 56% of its total proteins along with the majority of the vitamin A and minerals (chlorine, magnesium, potassium, sodium, and sulfur) in the egg (AEB, 1999). Egg white is qualified as a multi-purpose food ingredient and commercialized under various forms such as liquid solutions, pasteurized form, etc. But the more frequently encountered form is powder form obtained by several drying techniques such as spray, freeze, foam mat drying, etc. due to its short self-life (Talansier et al., 2009). Egg white powder was used as foaming agent and foaming stabilizer at several studies such as foam mat convective drying of Cantaloupe (Salahi et al., 2015), foam mat freeze-drying of apple juice (Raharitsifa and Ratti, 2010), etc. In addition, the egg white powder can be used as a drying agent in the food industry (Solval, 2011).

Foam mat drying is an alternative technique to drum, spray, and freeze-drying techniques to obtain food powders due to its suitability for all types of liquids and rapid drying at a lower drying temperature, high retention of nutrition, easy reconstitution, and being cost-effective (Sangamithra et al., 2014; Kudra and Ratti, 2006). In this technique, liquids or semi-liquid/solid foods are transformed into stable foams followed by drying under thin layer conditions (Abbasi and Azizpour, 2016; Sangamithra et al., 2014; Rajkumar et al., 2007). In order to reduce the surface tension between liquid-liquid or liquid-solid interphase and increase the stability of foams, various foaming agents (proteins) and stabilizers (polysaccharides) are generally used (Sangamithra et al., 2014). Foam mat drying rate is very high compared to other convective drying techniques due to the higher surface area (Sharada, 2013). A high-quality food powder can be obtained by the proper selection of the foaming method, agent, stabilizers, and time and also selected drying method and temperature (Sangamithra et al., 2014). There are several studies on the drying of egg white by using different drying techniques such as spray drying (Ayadi et al., 2008; Ma et al., 2013), foam mat freeze-drying (Mathukumaran et al., 2008a and b) and microwave-assisted foam mat drying (Çalışkan Koç and Çabuk, 2019). However, from the authors' knowledge, there is a paucity of literature investigating the effect of drying air temperatures on the quality characteristics of foam mat dried egg white powder. Kudra and Mujumdar (2002) and Araya-Farias and Ratti (2009) reported that the conventional drying methods are still widely preferred industrially as compared to novel technologies due to the simplicity of dryer construction, ease of operation, and status of familiarity. For this reason, the aim of this study is to determine the effect of different drying air temperatures on the drying behavior, effective moisture diffusivity, physical, powder, and functional properties of hot air assisted foam-mat dried egg white powder.

MATERIAL AND METHODS

Material

The commercial pasteurized liquid egg whites were obtained from Anako Egg and Products Food Industry Import, Export and Trade Co. Ankara, Turkey. Egg whites were kept under refrigeration (5±2°C) until the next step of the experiment.

Experimental Procedure

Foam Preparation

The egg foam was obtained by the method described by Mathukumaran et al. (2008a and 2008b). In order to obtain egg foam, fifty milliliters of egg white (+24±2°C) was added to the glass beaker (500ml) and a kitchen blender (1000W power, 30s, SHB 3107, Sinbo, Turkey) was used for making foam.

Convective Hot Air Drying

The egg white foam samples were dried in a convective hot air oven (Memmert, UF 110, Germany) at 60, 70, and 80°C temperature and at

20% ventilation rate. The total amount of egg white foam was 40.00±0.20g for each drying experiment. Samples were placed as a slab 35x50 cm (width x length, 2mm thickness, drying took place from one side) and located at the center of the convective hot air oven. The weight loss was measured every 10 min until the constant weight was reached. Then, the obtained pellets were ground in order to obtain egg white powder.

Drying Behavior and Drying Rate

The moisture ratio (MR) of egg white foam during convective hot air drying was calculated using the Eq. (1);

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad (1)$$

Where M_t, M_0, and M_e are the moisture content at any time, initial, and equilibrium (kg water (H_2O)/ kg dry matter (DM)), respectively.
Drying rate was defined as:

$$Drying\ Rate\ (DR) = \frac{\Delta X}{\Delta t * S} \qquad (2)$$

where X is the moisture content (kg H_2O/kg DM), t is the time (min), S is the total surface area of all egg white foam in one container (m^2) and DR is the drying rate (kg H_2O/kg DM.min.m^2) (Tekin and Başlar, 2018).

Calculation of Effective Moisture Diffusivity and Activation Energy

In order to calculate D_{eff} values, it is assumed that the moisture diffusion coefficient is the same in all directions (isotropic material) and shrinkage of the sample is negligible. The effective moisture diffusivity (D_{eff}) values of egg white foams were calculated by Fick's diffusion model as given in (Eq. 3).

$$MR = \frac{M_t - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} exp\left[-(2n-1)^2 \pi^2 \frac{D_{eff}}{4L^2} t\right] \qquad (3)$$

Where t is the time (s), D_{eff} is the effective moisture diffusivity (m^2/s), and L (m) is the thickness of samples. A limiting case of Eq. (2) was assumed and expressed in the logarithmic form as in Eq. (4);

$$\ln MR = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{4L^2}\right) t \qquad (4)$$

D_{eff} is typically calculated by plotting experimental MR in logarithmic form versus drying time. From the Eq. (4), a plot of lnMR versus drying time gives a straight line with a slope of (Eq. 5):

$$Slope = \frac{\pi^2 D_{eff}}{4L^2} \qquad (5)$$

The relation between the effective moisture diffusivity and drying temperature was assumed to be an Arrhenius function (Eq. 6).

$$D_{eef} = D_0 \exp\left(-\frac{E_a}{RT}\right) \qquad (6)$$

where D_0 is the pre-exponential factor of the Arrhenius equation in m^2/s, E_a is the activation energy in kJ/mol, R is the universal gas constant (R = 8.31451 J/mol.K), and T is the hot air temperature expressed in K.

Determination of Physicochemical Properties

The moisture and ash contents of the egg white powders were determined according to AOAC (2000) and AOAC (2005). The water activity and color values of the egg white powders were measured using a Testo-AG 400, Germany water activity measurement device and Konica Minolta CR-400, Japan colorimeter, respectively. Chroma, total color change (ΔE), browning (BI), and yellowness (YI) index values were calculated according to Pathare et al. (2013).

Determination of Powder Properties

Bulk and tapped densities, flowability (Carr Index (CI)) and cohesiveness (Hausner Ratio (HR)) values, wettability time, and hygroscopicity (%) analysis were performed according to the procedure described by Jinapong et al. (2008), Gong et al. (2008), and Cai and Corke (2000), respectively.

Determination of Functional Properties

Emulsification (Emulsification Activity (EA) and Stability (ES)) and foaming properties (Foam Holding Capacity (FC) and Stability (FS)), as well as water and oil holding capacities of foam mat dried egg white powders were determined according to Yasumatsu et al. (1972), Stone et al. (2015), and Liu et al. (2010), respectively.

Statistical Analysis

All experiments were performed in duplicate and measurements were performed in triplicate. Statistically significant differences between the samples were determined using ANOVA (analysis of variance, F-test for multiple samples or two samples with α = 0.05, SPSS 20.0, SPSS Inc., Chicago, IL, U.S.A.). Significant differences were indicated by different letters when the p-value was below 0.05.

RESULTS AND DISCUSSION

Drying Kinetics

The changes in moisture ratio values of egg white foam depending on drying time (min) is shown in Figure 1. The egg white foam showed a similar trend for all drying temperatures. The drying time of the egg white foam ranged between 30 min and 50 min and an increase in the drying air temperature resulted in a significant decrease in drying time (*P* <0.05). When the drying temperature increased, the moisture removal rate accelerated and thus, drying time reduced. It can also be stated that the drying air temperature is an important variable in the foam mat drying process. Similar findings were also observed by several researchers (Rajkumar et al., 2007; Kadam and Balasubramanian, 2011). Kadam and Balasubramanian (2011) reported that drying time of foam-mat dried of tomato juice powder ranged between 450 min to 510 min and decreased according to drying air temperature (60, 65, and 70ºC). According to Figure 1, it can also be stated that the moisture reduction rate of egg white foam was high until 30 min for 60ºC drying air temperature and 20 min for 70 ºC and 80ºC drying air temperatures. After these periods, the moisture removal rate stayed almost stable and reached the final moisture content. The freeze-drying time of egg white foam (25g sample, -40ºC condenser temperature, +20ºC heating plate temperature) was found to be as 20-24h by Mathukumaran et al. (2008b). By using convective hot air drying technique, the drying time of egg white foam could be significantly decreased compared to the freeze-drying technique.

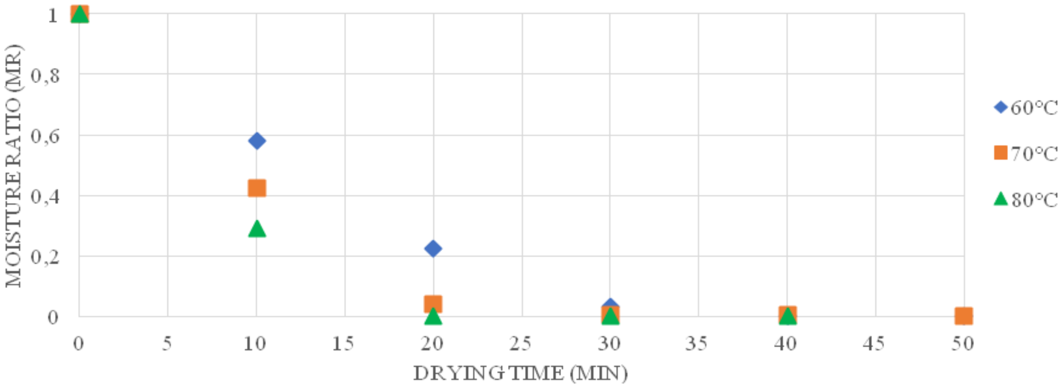

Figure 1. The changes in MR values of the egg white foam depending on drying time

The drying rates of egg white foam were calculated (kg H_2O/kg DM.min.m^2) and plotted against the free moisture content (kg H_2O /kg DM) as shown in Figure 2. It can be seen that drying took place in the falling rate period at all drying temperatures which indicates that the internal moisture diffusion phenomenon controlled the drying process except for the initial temperature-rise period. It may be due to the rapid removal of moisture from the thin surfaces of foams. Similarly, Rajkumar et al. (2007) reported that drying (batch-type thin layer cabinet dryer, at 60, 65, 70, and 75ºC) of foamed mango pulps with egg albumen occurred during the falling rate period with the rapid removal of moisture from the thin surfaces of foams. In addition, Çalışkan Koç and Çabuk (2019) reported that the overall drying process of the egg white foam (6.00±0.20g, 10.8 cm diameter, 2mm side thickness) took place in the falling rate periods for all microwave drying experiments (350W, 460W, 600W, and 720W) except for 120W. The drying rate values of egg white foam ranged between 0.1614-0.001, 0.1938-0.002, and 0.2245-0.002 kg H_2O /kg DM.min.m^2 for 60, 70, and 80°C drying air temperatures, respectively. The higher drying rate values were observed for the drying experiment which was performed at 80°C. The higher temperature difference between the drying medium and sample increases the heat transfer coefficient which is related to higher heat and mass transfer rate. In addition, the higher drying rate values were observed at the initial phase of the drying for all drying temperatures due to the higher moisture diffusion rate.

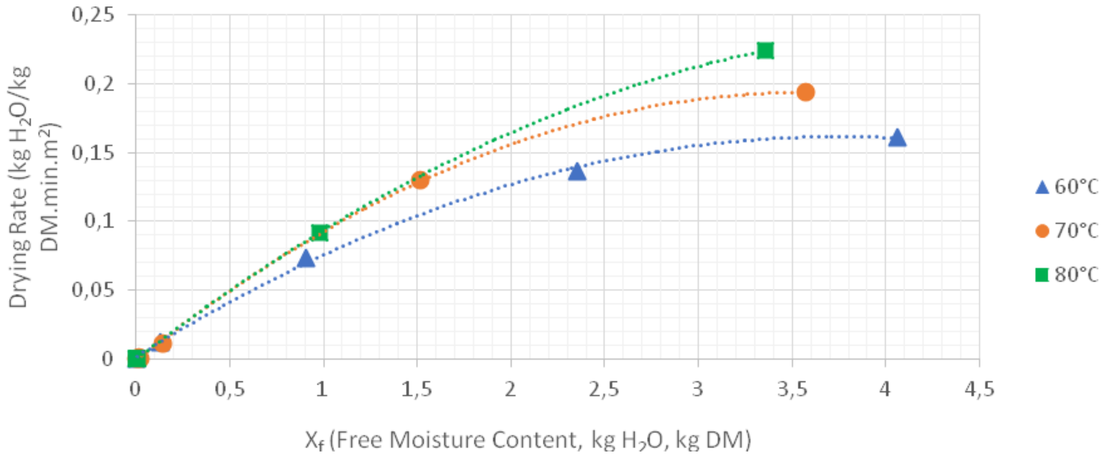

Figure 2. The drying rate (kg H_2O/kg DM*min*m^2) of egg white foam

The effective moisture diffusivity, pre-exponential factor, and activation energy values of foam mat dried egg white powders values are given in Table 1. According to the results, it can be stated that an increase in the hot air drying temperature resulted in an increase in the effective moisture diffusivity values, however, this increase was not found to be statistically significant ($P > 0.05$). The reasons for high effective moisture diffusion values of egg white foam may be due to a larger exposed surface area of egg white foam. Mathukumaran et al. (2008b) reported that the freeze-dried egg white foam with 0.125% xanthan gum had three effective moisture diffusivity values (2.677×10^{-8}, 5.962×10^{-8}, and 1.247×10^{-7} m^2/s (Average=7.036×10^{-8} m^2/s) where the egg white foam without xanthan gum had only two effective moisture diffusivity values (2.413×10^{-8} and 3.781×10^{-8} m^2/s (Average=3.097×10^{-8} m^2/s)). In this study, the D_{eff} values of convective hot air assisted foam mat dried egg white powders were found to be higher than the results of Mathukumaran et al. (2008b). It may be due to a higher drying rate of convective hot air drying technique compared to the freeze-drying technique. In addition, the egg white foam had one effective moisture diffusivity value for all drying temperatures.

The activation energy (E_a) is related to the required energy to facilitate moisture diffusion. Lower E_a values indicate that the lower energy is necessary for moisture diffusion (Tekin and Başlar, 2018). The pre-exponential factor and activation energy values for hot air assisted foam mat dried egg white foam values were calculated to be as 2.8960×10^{-4} m^2/s and 13.81kJ/mol, respectively.

Physicochemical Properties

Physicochemical properties of convective hot air assisted foam mat dried egg white powders are shown in Table 2. The moisture content values of the powders were found to be lower than 10%.

The moisture content values decreased when drying air temperature increased from 60°C to 70°C (P >0.05), however, the opposite effect was observed for the further increase (P <0.05). It may be due to crust formation which did not let to remove the moisture from the egg white foam. The moisture content values of foam mat freeze-dried egg white powder with xanthan gum and without xanthan gum were found to be as 7.74% and 8.47% (wet basis), respectively (Mathukumaran et al., 2008b). The different drying techniques may be the reason for different moisture content values. The ash contents of the samples were ranged between 4.38%-4.43% and were not significantly changed depending on the drying air temperature (P >0.05). Ayadi et al. (2008) reported that the ash content of spray-dried whole egg powder and egg white powder were 6.13 ± 0.11 and 5.69 ± 0.09 g/100g dry basis, respectively. The results (4.70-4.76 g/100g dry basis) obtained in this study were found to be slightly lower compared to the findings of Ayadi et al. (2008). The water activity values of egg white foam were found to be lower than 0.6 which can be acceptable as microbiologically safe. The water activity values decreased depending on an increase in the drying air temperature (P <0.05).

Table 1. Effective moisture diffusivity, pre-exponential factor, and activation energy values of foam mat dried egg white powders (n=3).

Drying Air Temperature (°C)	Effective Moisture Diffusivity (D_{eff}, m²/s)	R²	Pre-Exponential Factor (D_0, m²/s)	Activation Energy (E_a, kJ/mol)
60	$1.9879\times10^{-6}\pm5.1637\times10^{-7}$ ^{a}	0.9208±0.0531	2.8960×10^{-4}	13.81
70	$2.2719\times10^{-6}\pm3.4424\times10^{-7}$ ^{a}	0.9373±0.0182		
80	$2.6370\times10^{-6}\pm1.7212\times10^{-7}$ ^{a}	0.9158±0.0214		

$^{a-c}$ Different letters in the same column indicate a significant difference between the samples at P <0.05.

Table 2. Physical properties of foam mat dried egg white powders (n=3).

Drying Air Temperature (°C)	Moisture Content (%, Wet Basis)	Ash Content (%)	Water Activity	Chroma	Yellowness Index (YI)	Browning Index (BI)
60	6.44 ± 0.80^{ab}	4.40 ± 0.14^{a}	0.458 ± 0.01^{b}	20.30 ± 0.02^{c}	31.24 ± 0.03^{c}	20.57 ± 0.02^{c}
70	6.30 ± 0.21^{a}	4.38 ± 0.64^{a}	0.455 ± 0.02^{b}	17.94 ± 0.05^{a}	27.10 ± 0.08^{a}	17.48 ± 0.06^{a}
80	6.97 ± 0.26^{b}	4.43 ± 0.74^{a}	0.438 ± 0.01^{a}	18.99 ± 0.07^{b}	28.67 ± 0.08^{b}	18.33 ± 0.05^{b}

$^{a-c}$ Different letters in the same column indicate a significant difference between the samples at P <0.05.

The color values of egg white foam are given in Figure 3. The effect of drying air temperature on the color values was found to be significant (P <0.05). The L* and a* values of egg white powders significantly increased when the drying air temperature increased from 60°C to 70°C, however, further increase resulted in a significant decrease (P <0.05). But, the opposite effect was observed for b* values of powders. The a* values of egg white powder was found to be on the negative scale which indicates the green color. The chroma, YI, and BI values were calculated and results are given in Table 2. Similar to b* values, the chroma, YI, and BI values decreased when drying air temperature was increased from 60°C to 70°C, however, the opposite effect was observed for further increase (P <0.05).

Powder Properties

The powder properties of egg white powder are illustrated in Table 3. The wettability times of egg white powders changed between 453.50s and 706.25s and significantly decreased depending on the increasing drying air temperature (P <0.05). The higher water holding capacity of the samples which were dried at 80°C may also be the reason for fast wetting behavior (Table 4). Çalışkan Koç and Çabuk (2019) reported that the wettability times of microwave-assisted foam mat dried egg white powder ranged between 1034.00s and 1721.50s. According to this finding, it can be stated that the convective hot air drying technique resulted in faster wettable egg white powder compared to the microwave drying technique. The different drying techniques, moisture content values, and surface properties may be the reason for different wetting behavior. Higher bulk density values are desired because of low packaging and transportation costs. For this reason, the egg white powder dried at 60°C has the advantages of low packaging and transportation costs due to significantly higher bulk density values compared to other drying temperatures ($P < 0.05$). The bulk and tapped density values of egg white powders significantly decreased depending on an increase in the drying air temperature ($P < 0.05$). The bulk and tapped density values of egg white powders were in line with Çalışkan Koç and Çabuk (2019) who reported that the bulk and tapped density values of egg white powder ranged between 282.33 and 331.35kg/m^3 and 416.68 and 514.58 kg/m^3, respectively. The egg white powder showed fair flow characteristic and high cohesiveness which may be due to an intermediate moisture content values of the powders. Similar findings were also obtained by Çalışkan Koç and Çabuk (2019) for microwave-assisted foam mat dried egg white powder. The higher CI and HR values were observed for the powders which were dried at 80°C. It may be due to the stickiness effect of moisture. Iqbal and Fitzpatrick (2008) and Fitzpatrick et al. (2007) reported that high moisture content increases the cohesion between powder particles and resulting in lower flowability. In order to improve the flow properties of egg white powder, different types of food-grade additives such as maltodextrin, gum Arabic, whey powder, etc. which improve the flow properties can be added or agglomeration process can be applied to the obtained powders. According to Tables 2 and 3, it can also be stated that the moisture content and hygroscopicity have an inverse proportional relationship. It may be due to the high-moisture concentration gradient between the egg white powders and the surrounding atmosphere.

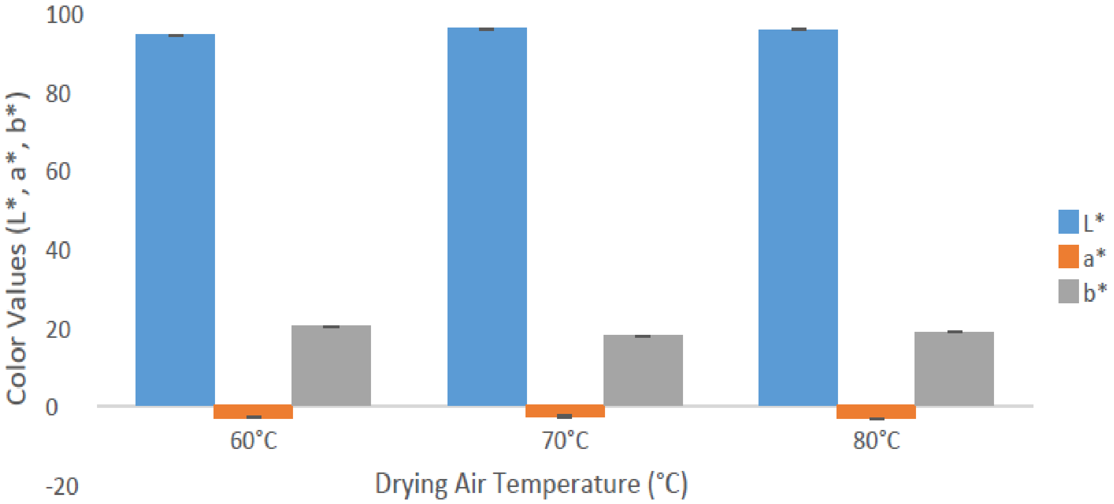

Figure 3. Color values of foam mat dried egg white powders.

Table 3. Powder properties of foam mat dried egg white powder (n=3).

Drying Air Temperature (°C)	*Wettability Time (s)*	*Bulk Density (kg/m^3)*	*Tapped Density (kg/m^3)*	*Flowability (Carr Index)*	*Cohesiveness (Hausner Ratio)*	*Hygroscopicity (%)*
60	706.25 ± 91.31^{c}	323.12 ± 22.92^{b}	471.89 ± 14.43^{b}	31.53±4.24 (Fair) ^{a}	1.47±0.09 (High) ^{a}	12.24 ± 0.32^{a}
70	596.33 ± 76.89^{b}	259.76 ± 32.63^{a}	385.60 ± 52.07^{a}	30.56±1.68 (Fair) ^{a}	1.46±0.04 (High) ^{a}	13.44 ± 0.52^{c}
80	453.50 ± 75.90^{a}	230.70 ± 10.92^{a}	356.08 ± 36.53^{a}	34.92±3.92 (Fair) ^{a}	1.54±0.09 (High) ^{a}	12.90 ± 0.14^{b}

$^{a\text{-}c}$ Different letters in the same column indicate a significant difference between the samples at $P<0.05$.

Functional Properties

The functional properties of egg white foam are given in Table 4. The water holding capacity (WHC) of proteins is important due to its effect on physical (elasticity, swelling, etc.), chemical (emulsification, etc.) and sensory (juiciness, etc. properties of foods (Wong and Kitts, 2003). Similar to moisture content values, the WHC of egg white powders significantly decreased when the drying air temperature increased from 60°C to 70°C, however, further increase (70°C to 80°C) resulted in a significant increase ($P<0.05$). It may be due to higher protein denaturation at the higher drying temperatures. Wagner and Anon (1990) reported that the denatured protein entraps a significant amount of water. Ndife et al. (2010) reported that the water holding capacity of oven-dried whole egg powder, egg yolk, and white powders were 1.60g, 0.50g, and 1.80g, respectively. The WHC of commercial spray-dried egg white powder was also found to be 1.68 ± 0.06 g H_2O/ g protein (Wong and Kitts, 2003). The differences between the results may be due to the different drying techniques, analysis methods, material, etc. Opposite to WHC results the OHC values of egg white powders firstly increased when the drying air temperature increased from 60°C to 70°C, however, further increase resulted in a decrease ($P<0.05$). It was previously reported that WHC and OHC can be changed due to denaturation and partial unfolding of the protein structure (Ayadi et al. 2008). Han et al. (2019), Van Der Plancken et al. (2006), and Folawiyo and Apenten (1997) also found that the content of total dissociated sulphydryl groups increased, ovalbumin and lysozyme unfolded by heat treatment contributing to the exposition of hydrophobic groups buried in the core of proteins and increasing surface hydrophobicity thus influencing the binding ability of water and oil molecules.

Significant differences in emulsifying and foaming properties were detected among treated samples ($P<0.05$). Egg white powder dried at 70°C had the lowest ES, while this sample obtained the highest FS. Egg white powder treated at 70°C had the highest emulsion activity, which means that it had the best ability to produce a cohesive protein layer at the oil-water interface. On the other hand, it was observed that ES followed an opposite trend and the lowest ES was calculated at 70°C showing that at that temperature protein molecules were unable to form a well-ordered network structure to form stable emulsions. This might be related to the re-arrangement of protein structure during the heating procedure involved in ES measurement assay. Moreover, dry heating might also induce partial hydrolysis of egg white proteins. It is known that protein hydrolysates can migrate to the oil-water interface more efficiently due to lower molecular size whereas protein hydrolysates could form less stable network structure due to fewer hydrophobic binding sites (Pokora et al., 2013), resulting in a relative worse ES of protein hydrolysates. In the current study, it was clearly observed that functional properties change significantly ($P<0.05$) by during drying and are influenced by processing conditions. From Table 4, it can be observed stated that when the heating temperature was 70°C foam holding capacity decreased followed by a further increase to 139.00±18.42% when temperature increased. The increased temperature might cause a reduction in the viscosity of the continuous phase in stabilizing foam structure (Kinsella, 1981). In contrast to our research, Ibanoğlu and Erçelebi (2007) obtained the foamability 80°C when effects of temperature (65, 70, 75, and 80°C) and protein concentration on egg white foam was investigated. In terms of FS, no significant ($P > 0.05$) differences could be found between the different treatments applied.

Table 4. The functional properties of foam mat dried egg white powders (n=3).

Drying Air Temperature (ºC)	Water Holding Capacity (%)	Oil Holding Capacity (%)	Emulsification Activity (%)	Emulsification Stability (%)	Foam Holding Capacity (%)	Foam Holding Stability (%)
60ºC	299.5±13.50^{a}	145.67±10.25^{a}	256.94±2.55^{ab}	136.00±2.87^{a}	140.00±0.00^{a}	88.57±0.00^{a}
70ºC	252.50±13.00^{a}	202.50±9.19^{b}	265.31±1.80^{a}	106.69±3.45^{b}	124.00±4.00^{b}	90.42±2.92^{a}
80ºC	300.00±15.00^{a}	196.00±1.41^{b}	256.97±1.10^{b}	137.84±2.67^{a}	139.00±18.42^{a}	84.11±7.67^{a}

$^{a\text{-}c}$ Different letters in the same column indicate a significant difference between the samples at $P < 0.05$.

CONCLUSION

In this study, it was observed that hot air assisted foam mat drying is a suitable process to obtain egg white powder which can be used as a food ingredient especially in the bakery industry for its foaming, gelling, and encapsulating properties. The moisture contents of foam-mat dried egg white powders are below 10% which is sufficient to make foods microbiologically safe. The ash content of the samples was not significantly changed depending on the drying air temperature ($P > 0.05$). Results indicated that the bulk and tapped density values and average wettability times of foam-mat egg white powders significantly decreased depending on the increase of drying air temperature ($P < 0.05$). Water holding capacity values were first decreased down when the temperature increased to 70°C and then increased with an increase in the temperature of treatment. However, the opposite effect was observed for oil holding capacity values. Heat treatment showed to have an influence on egg white protein conformation, which impairs their sensitivity to water and oil binding. The emulsification activity was also significantly influenced by the change in drying temperature and followed a similar trend as oil holding capacity ($P < 0.05$). The strongest effects are rather observed at 70°C. The effect of the different drying processes on the chemical composition and the effect of storage conditions on the physical, chemical, and powder properties of foam-mat dried egg white powder could be studied in further studies.

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