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THE USE OF REFRACTANCE WINDOW-DRIED EGG POWDER IN CAKE PRODUCTION

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ABSTRACT
The study aimed to evaluate the use of refractance window-dried egg powders in cake production. It was found that liquid egg white (WL) resulted in the lowest batter density of 1.05 g/mL, followed by egg white powder (WP) at 1.16 g/mL. The highest specific volume was determined in WL samples at 2.71 ml/g, followed by WP samples at 2.46 mL/g. In addition, the use of powdered eggs reduced baking loss but also caused a decrease in the crumb lightness value. Furthermore, the usage of WP had a positive effect on the hardness value of cake samples, which decreased from 884.01 g to 720.53 g. Finally, the alternative use of egg powder had a positive effect on crumb appearance, increasing both cell count and total cell area. Therefore, the incorporation of powdered eggs by refractance window drying instead of liquid eggs in cake production can be considered an applicable approach due to the various benefits it offers.
Keywords: Techno-functional properties, egg powder, refractance window drying, cake

KIRINIM PENCERELİ KURUTUCU İLE ÜRETİLMİŞ TOZ YUMURTANIN KEK ÜRETİMİNDE KULLANIMI

ÖZ
Bu çalışmanın amacı, kırınım pencereli kurutma ile kurutulmuş yumurta tozlarının kek üretiminde kullanımının araştırılmasıdır. Çalışmada, en düşük hamur yoğunluğunun 1.05 g/mL ile sıvı yumurta akı (SYA) kullanılarak üretilen keklerde elde edildiği ve bunu 1.16 g/mL ile yumurta akı tozu (TYA) kullanılan kek örneklerinin takip ettiği bulunmuştur. En yüksek özgül hacim 2.71 ml/g ile SYA örneklerinde belirlenirken, bunu 2.46 mL/g ile TYA örnekleri izlemiştir. Buna ek olarak, toz yumurta kullanımı pişme kaybını azaltmış, ancak aynı zamanda kabuk parlaklık değerinde bir düşüşe neden olmuştur. Ayrıca, TYA kullanımının kek örneklerinin sertlik değeri üzerinde olumlu bir etkisi olmuş ve 884.01 g değerinden 720.53 g değerine düşmüştür. Son olarak, yumurta tozunun alternatif kullanımı, hem gözenek sayısını hem de toplam gözenek alanını artırarak kek içi görünümü üzerinde olumlu bir etkiye sahip olmuştur. Bu nedenle, kek üretiminde sıvı yumurta yerine kırınım pencere ile üretilmiş toz yumurta kullanımı, sunduğu çeşitli faydalar nedeniyle uygulanabilir olarak değerlendirilebilir.
Anahtar kelimeler: Kek kalite özellikleri, toz yumurta, kırınım pencereli kurutma, kek

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INTRODUCTION

The egg is considered a vital source of high-quality protein for human nutrition due to its well-balanced essential amino acid composition and high digestibility. The annual global consumption rate of hen eggs is nearly 150 per person (Gautron et al., 2022). Although the consumption of eggs in their shell form has decreased over the years, the consumption of processed egg products has increased (Rao and Labuza, 2012). Apart from its high nutritive value, the egg is widely used as the primary ingredient in bakery products due to its superior technological properties, such as foaming and emulsion-forming capacity. In particular, egg whites are used in aerated for emulsion-forming and puffed products as foaming agents (Chang et al., 2020). The egg is considered an essential ingredient in cakes and other sweet bakery products due to its unique foaming, solubility, emulsification, and coagulation qualities. Eggs play a critical role in baked goods by serving several purposes, including binding, leavening, tenderizing, and emulsifying the mixtures, as well as contributing flavour, colour, and nutritional content (Ratnayake et al., 2012).

In industrial applications, pasteurized liquid egg white or whole egg is generally preferred due to difficulties and hygienic problems associated with processing of shell eggs. However, the short storage time of pasteurized eggs and cold-storage requirements have encouraged bakery producers to seek new alternatives to liquid eggs. From a technological perspective, powdered forms of the eggs are much more suitable for application than liquid eggs as they have a longer shelf life and are more convenient for long-distance transport. Furthermore, egg powders enable precise dosing methods to be used in the formulation during large-scale production (Lechevalier et al., 2013; Chang et al., 2021). The demand for egg powder is increasing as it has been realized that it is useful in the production of bakery foods, bakery mixes, mayonnaise and salad dressings, confections, ice cream, pasta, and many convenience foods (Rao and Labuza, 2012). However, the usage of powdered egg products is still met with some reservations due to the possibility of deterioration of solubility, foaming and emulsifying capacity and stability (Chang et al., 2021). Therefore, finding practical ways to enhance the functional capabilities of powdered egg products for effective use in food production is crucial (Chang et al., 2020).

Egg powders were first developed for the military due to their practical advantages during times of war (Lechevalier et al., 2013). By dehydration, the moisture content and water activity of liquid eggs are decreased to less than 5% and 0.2, respectively, thereby extending the shelf life to 1-2 years. Furthermore, when considering the dry matter of liquid egg yolk and white, drying offers several advantages. To obtain 1 kg of dried egg yolk, 2.3 kg of liquid is required, and 8.5 kg of liquid egg white is required to obtain the same amount of dry matter. Therefore, egg white powder is much more useful in terms of transportation compared to liquid forms (Lechevalier et al., 2013). Several drying techniques can be applied in the production of powdered egg products, with spray drying being the most commonly used technique. However, the high temperatures used during spray drying can negatively affect the functional properties of egg proteins. Additionally, spray-dried egg powder has poor solubility, which results in particle agglomeration in aqueous media. To overcome this problem, the surface of the egg powder is coated with sugar solutions (Lechevalier et al., 2013). Freeze-drying and pan-drying are other commonly used techniques for producing egg powder (Chauhan and Sharma, 2003). Pan-drying was developed for drying egg white in flake or granule form and preferred for making aerated confectionaries (Lechevalier et al., 2013). Although freeze-drying produces high quality egg powder, the cost of the process limits the usage in large scale. Therefore, the industry is seeking novel drying methods that can be applied for production of egg powder without any significant change in technological properties compared to liquid counterparts.

During the production of egg powder, process parameters can alter rheological and interface functions. Foaming capacity is one of these critical functions, as it provides the desired structure and texture with greater volume to the final product. Previous studies demonstrated that mid-heat treatment can improve the foaming ability of egg white by increasing its surface hydrophobicity. However, thermolabile egg white proteins, such as conalbumin, can denature and become insoluble (Franke and Kiebling, 2002; Song et al., 2009). Consequently, some authors have argued that powdered egg products cannot meet the demands of cakes and need to be modified (Tang et al., 2022). While most previous studies have focused on the drying of egg white, yolk and whole egg and determined changes in technological properties, the effects of this replacement on the acceptability of the product in terms of texture, volume and sensory features have not been studied. Therefore, the data published to date is insufficient to decide whether powdered egg products meet the special requirements of food producers. To address this gap, the present study aims to evaluate the usability of egg powders produced by refractance window drying, a new generation drying technique, in the production of cakes as an alternative to liquid counterparts.

MATERIALS and METHOD

Production of Egg Powder

In egg powder production, pasteurized liquid white and whole egg (Anako, Konya, Türkiye) were used. Liquid egg samples were foamed by a mixer (Hobart, N50, Germany) for 5 min, and spread on a dryer film of pilot-scale refractance window dryer (InfraRWD, NFDS, Türkiye) with 2 mm thickness. The liquid egg white was dried at 80°C for 10 min and the liquid whole egg was dried at 90°C for 5 min. The drying temperatures and time were determined by preliminary studies. The egg powders were milled and stored in sealed bags at refrigeration temperature till cake production.

Production of Cake Samples

In the designed study, four different formulated cakes were produced using liquid egg white, liquid whole egg, powdered egg white, and powdered whole egg. The liquid egg white was separated from the egg yolk and the chalaza was removed. The cake mix was prepared with an equal ratio of flour, egg, vegetable oil, and sugar. The vanilla and baking powder were added as 0.6% of the cake mix (Arslan-Tontul et al., 2019). The egg powders were used in the mix formulation after being suspended in water with the same dry matter content as liquid egg samples. For this purpose, 12 g white egg powder was resuspended with 88 g water, and 25 g whole egg powder was resuspended with 75 ml water. To prepare the cake mix, liquid egg samples or dehydrated egg powders and sugar were mixed for 5 min by a blender (Hobart, N50, Germany), remained ingredients were added and mixed again for 5 min. The cake mix was weighed 50 g into the molds and baked at 200°C for 20 in an electrical oven (Simens, HN678G4S6, Germany). The baked cake samples were cooled to room temperature and analysed.

Determination of mix density, cake height, and weight

Mix density was calculated by determination of the volume of 10 g batter. The height and weight of the cake were measured using a digital calliper and analytical balance.

Baking loss

Baking loss of the liquid and egg powder containing cake was calculated by weighing the batter (W_f) and cake (W_c) (Singh, Benjakul, & Karnjanapratum, 2019).

Baking loss % (w/w) = $((W_f - W_c)/W_f) \times 100$

Specific volume

The specific volume of cake samples was evaluated by the rapeseed displacement method and calculated through the volume/mass ratio and expressed in mL/g (AACC, 2000).

Colour Measurement

L*, a*, and b* colour values of the cake crust were measured by the colour meter (Chroma meter CR-400, Konica Minolta, Japan). Parameter L* represents the light-dark spectrum with a range of 0 (black) to 100 (white). Parameter a* represents red-green colour with positive a* values indicating redness and negative a* values indicating greenness. Parameter b* represents yellow-blue colour with positive b* values indicating yellowness and negative b* values indicating blueness (Arslan-Tontul et al., 2022).

Texture Profile Analysis

The texture profile analysis (TPA) of the cake was determined by a texture analyser (TA-XT plus, Stable Micro Systems, Surrey, UK). The sample was sliced to 2.5 cm and TPA was performed by using an aluminum 25 mm diameter cylindrical probe (P36/R), 5-kg load cell, 50% penetration depth, at a compression rate of 3 mm/s and 5 s gap between two compressions. Pre and post-test speeds were 2 mm/s and 3 mm/s, respectively (AACC, 2000).

Digital image analysis

Image analysis was carried out by cake slices. The image of the slice was captured with a flatbed scanner (M2070 HP laserjet scanner, USA), and saved as bitmap files and sRGB colour. A square field of image (4x4 cm) was cropped and converted to greyscale (8-bit) using ImageJ software (National Institutes of Health, Bethesda, MD, USA). The images were pre-processed (contrast enhancement, sharpening, and noise reduction) to improve image quality, and the total number of cells and total cell area was determined after the threshold intensity was adjusted (Arslan-Tontul et al., 2022).

Statistical Analysis

The cake production was duplicated, and analysis was carried out in two parallels. The data were subjected to analysis of variance, and appropriate mean separation was conducted using Duncan's Multiple-Range Test ($p<0.05$). All statistical calculations were performed by SAS Statistical Software (SAS Institute Inc., Cary, NC, USA).

RESULTS and DISCUSSION

Physical quality characteristics of batter and cake samples

The mix density of batters produced by liquid egg and egg powder is given in Table 1. In general, the density of batter formulated using the white parts of the egg was lower than that produced by the whole egg. Statistically, the density of batter formulated using liquid and powder whole egg was in a similar range ($p>0.05$). The lowest batter density was obtained when using of liquid egg white (1.05 g/mL), followed by egg white powder at 1.16 g/mL. The lower batter density is expected to result in high air retention, which means high foaming capacity. It has been reported that the greater air content of the batter caused the lower density (Tang et al., 2022). Foam volume, which is connected to bubble formation and stability, can be used to describe foaming properties. The final foaming capacity during foam formation depends on the pace of protein unfolding and adsorption at the interface. Hydrophobic and hydrophilic groups on the protein molecule eventually adsorb to the air-water interface during whipping and partially unfold there. Thus, it forms the batter density (Chang et al., 2020). This result shows that there is a limited decrease in the foaming capacity of egg white when dried by the refractance window dryer. However, previous studies have indicated that drying increases the foaming capacity of egg white. Ayadi et al. (2008) found that the foaming capacity of the dried egg white at 120°C is four times higher than that of the fresh sample, but increased drying temperatures caused a decrease in foaming capacity. Tang et al. (2022) reported that batter density was higher in powdered egg used formulates than in liquid white eggs. This discrepancy may be attributed to the diversity of drying techniques.

After baking, the changes in height and weight of the cake were determined (Table 1). In contrast to batter density, the measurements of height and weight were statistically similar in cake samples produced using liquid and powdered egg white. The lowest height was measured in the sample containing liquid egg white (EL) at 36.88 mm, and cakes containing egg powder and liquid egg white were in a similar range (44.98-48.96 mm). After baking, the weight of the cake was significantly affected by the use of liquid or powdered egg usage ($p<0.05$). In general, the weight of cake samples produced using egg white was higher than that of the samples containing whole egg. The weight of WL and WP were measured as 45.07 g and 45.32 g, respectively. This result is attributed to the high water-holding capacity of egg white proteins. On the other hand, the weight of EP was measured as 43.93 g, which was higher than EL (42.94 g). Additionally, these results showed that refractance window dried egg powder can be used as an alternative to the liquid egg in cake production without any deterioration in physical features.

Table 1. Some physical properties of cake samples

Features	Samples			
	WL	WP	EL	EP
Batter density (g/mL)	1.05 ± 0.01[c]	1.16 ± 0.05[b]	1.29 ± 0.01[a]	1.24 ± 0.03[a]
Height (mm)	48.96 ± 0.35[a]	45.50 ± 1.10[a]	36.88 ± 0.81[b]	44.98 ± 3.42[a]
Weight (g)	45.07 ± 0.17[a]	45.32 ± 0.20[a]	42.94 ± 0.10[c]	43.93 ± 0.41[b]
Specific volume (mL/g)	2.71 ± 0.28[a]	2.46 ± 0.12[ba]	1.94 ± 0.05[b]	1.85 ± 0.07[b]
Baking loss (%)	9.86 ± 0.33[bc]	9.72 ± 0.77[c]	14.13 ± 0.21[a]	12.15 ± 0.82[ba]

WL: Liquid egg white, WP: Egg white powder, EL: Liquid whole egg, EP: Whole egg powder. The superscript letters, in the same line, indicate that are significantly different by Duncan's multiple range test ($P<0.05$).

The specific volume is an important quality parameter for bakery products as it indicates higher gas retention and a softer crumb texture in the final product. Furthermore, consumers tend to prefer foods with higher volume. The use of liquid or powdered eggs had a significant impact on the specific volume of cakes ($p<0.05$, Table 1). The main difference in the specific volume of cakes was obtained between egg white and whole egg. The highest specific volume was determined in WL samples at 2.71 ml/g, followed by WP samples at 2.46 mL/g. This result was considered well-correlated with batter density. The specific volume of cake is positively correlated with the foaming capacity and stability of the mix. Well-aerated and stable foams are expected to result in high specific volume. During whipping, egg protein groups are exposed to the gas and liquid phases, respectively. The viscoelasticity of the water/gas interface, which is produced by the protein-protein interaction, is correlated with the stability of the created foam. The proper protein transition may improve protein-protein interaction at the interface, decrease unfolding time, and increase adsorption rate, all of which benefit foaming properties (Chang et al., 2020). In the present study, although the weight and height of cakes formulated with liquid and powdered egg white were similar, it was considered that drying affected the functional properties of egg white proteins to a limited extend. However, in most studies, heat treatment on egg white proteins has been reported to improve their foaming ability because the denatured proteins adsorb more easily to the air bubble surface (Song et al., 2009).

From an economic standpoint, baking loss is a significant disadvantage to the production process due to both the higher batter volume handling during commercial procedures and the loss of product weight (Ratnayake et al., 2012). The use of powdered egg white significantly affected the baking loss ($p<0.05$), and the lowest loss value was determined in WP as 9.72%. Additionally, the highest cooking loss was obtained in EL at 14.13%, followed by EP at 12.15%. These results suggest that the denaturation occurring in the drying process may decrease the water release ratio of egg proteins and increase their water retention capacity. Similar results were reported by previous studies. Xu et al. (2022) found that the weight loss of cake produced by egg yolk powder ranged from 8.39% to 10.02%. Ratnayake et al. (2012) found that the baking loss values of yellow cakes produced by liquid and dried whole eggs were in the similar range of 8%. The authors also declared that none of the egg replacers were able to produce acceptable quality products at 100% (w/w) replacement of dry egg in the formulation.

Crumb and crust colour features

Colour is a crucial factor in food products as it reflects freshness and baking quality, which can affect consumer choices (Xu et al., 2022). The colour of foods depends on various factors such as ingredient interactions and/or changes, and heat-induced colour changes during processing (Ratnayake et al., 2012). The crumb and crust colour of samples are presented in Table 2. The L* and b* colour values of the crust were insignificantly affected by egg powder usage (p>0.05), and changed between 52.32-59.37 and 25.37-26.75, respectively. On the other hand, egg powder usage significantly affected the redness of the crust, and the highest a* value was detected in EL as 12.66.

The usage of egg powder led to a decrease in crumb lightness value. The highest L* value was detected in cake formulated by the liquid whole egg at 73.80, while the lowest lightness was observed in WP and EP. Additionally, a* colour values were also significantly affected, and egg powder usage led to an increase in redness value. This result may be attributed to Maillard-related product formation during the drying of egg powders. Furthermore, the b* value was lower in cake samples produced by liquid or powdered egg white. A similar result was also reported by Song et al. (2009) who investigated the usage of irradiated liquid or powder eggs in angel cake production. The authors found that the usage of egg powder increased the a* value and decreased the b* colour value. Ratnayake et al. (2012) reported that the crust colour of yellow cakes produced by dried and liquid whole egg was similar; however, using dried egg powder decreased crumb a* value and increased L*.

Table 2. Colour and texture features of cake samples

Features	Samples			
	WL	WP	EL	EP
Crust colour				
L*	53.09 ± 2.51^{a}	59.37 ± 4.09^{a}	53.96 ± 0.85^{a}	52.32 ± 7.61^{a}
a*	10.23 ± 1.42^{ba}	6.73 ± 0.93^{b}	12.66 ± 0.29^{a}	10.43 ± 2.12^{ba}
b*	26.43 ± 0.54^{a}	26.75 ± 0.12^{a}	25.37 ± 1.10^{a}	26.32 ± 3.99^{a}
Crumb colour				
L*	68.84 ± 1.27^{ba}	65.44 ± 1.19^{b}	73.80 ± 2.31^{a}	66.20 ± 1.53^{b}
a*	-1.93 ± 0.19^{ba}	-0.62 ± 0.66^{a}	-3.81 ± 0.64^{b}	-1.31 ± 0.20^{a}
b*	14.77 ± 0.17^{c}	16.48 ± 1.65^{c}	25.84 ± 0.33^{a}	21.65 ± 0.04^{b}
Texture profile				
Hardness	884.01 ± 39.56^{a}	720.53 ± 20.06^{b}	618.62 ± 3.77^{c}	568.43 ± 1.44^{c}
Springiness	0.94 ± 0.01^{a}	0.89 ± 0.01^{b}	0.86 ± 0.00^{c}	0.88 ± 0.00^{b}
Cohesiveness	0.77 ± 0.00^{a}	0.67 ± 0.00^{b}	0.58 ± 0.00^{c}	0.55 ± 0.01^{d}
Chewiness	639.25 ± 18.75^{a}	425.34 ± 13.84^{b}	318.64 ± 12.26^{c}	274.38 ± 0.77^{c}
Resilience	0.32 ± 0.01^{a}	0.25 ± 0.01^{b}	0.19 ± 0.01^{d}	0.21 ± 0.01^{c}

WL: Liquid egg white, WP: Egg white powder, EL: Liquid whole egg, EP: Whole egg powder. The superscript letters, in the same line, indicate that are significantly different by Duncan's multiple range test ($P<0.05$).

Texture profile

The texture profile results are presented in Table 2. The usage of powdered egg white had a positive effect on the hardness value of cake samples, decreasing it from 884.01 g to 720.53 g. Additionally, the hardness value of EL and EP was in a statistically similar range. Similar results were also reported by previous studies. Song et al. (2009) reported that the hardness value of cake decreased with the usage of egg white powder. Ratnayake et al. (2012) reported similar hardness values for liquid or dried whole eggs; however, after 7 days of storage, dried eggs showed higher hardness. Zarringhalami et al., (2021) reported that the hardness values decreased by increasing egg white powder amount from 10 to 25% in the gluten-free bread samples. This result was attributed to the reduction of surface tension by egg white and the stabilization of air bubbles in the batter, thereby reducing hardness and improving texture (Han et al., 2019). However, contrary results have also been reported such as

Tang et al. (2022) who found that the hardness value increased by egg white powder usage instead of liquid white egg, while elasticity decreased.

Likewise, the usage of egg powder decreased the springiness value of cake samples along with hardness. The lowest springiness value was measured in EL at 0.86. Cakes produced with whole egg had lower cohesiveness value than those produced with egg white powder, which caused a more cohesive crumb texture. The highest cohesiveness values were detected in WL at 0.77.

Similar to the cohesiveness value, chewiness was affected by both liquid-powdered and white-whole forms of the egg. The usage of egg white powder led to a decrease in the chewiness of the cake from 639.25 to 425.34. Additionally, the usage of liquid or powdered whole eggs had an insignificant effect on crumb chewiness. Similar results were also obtained in resilience value.

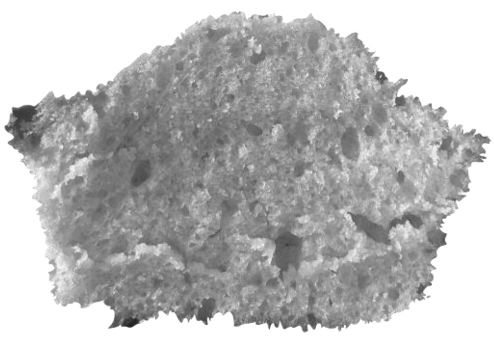
Image analysis

The alternative usage of egg powder had a positive effect on crumb appearance and increased both cell count and total cell area. The highest cell count and total cell area were detected in WP at 3304 and 97430.50 mm^2, respectively. These results are considered promising because the image structure improves when liquid egg products changed to powder forms. During the baking process, the structure of the cake is formed by the pasting of starch and the solidification of egg white protein, while sugar controls the rise and fall of the cake (Wilderjans et al., 2008). Therefore, the structure of egg protein is directly correlated with crumb appearance.

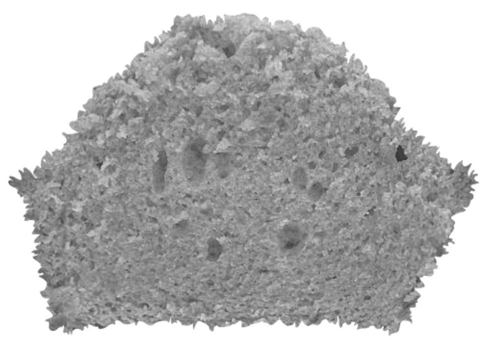
Table 3. Crumb cell count and total cell area of cake samples

Cake	Crumb cell count	Total cell area (mm^2)
WL	2947.50 ± 176^{ba}	43377.50 ± 150^{bc}
WP	3304.00 ± 150^{a}	97430.50 ± 163^{a}
EL	2223.50 ± 23^{b}	24271.50 ± 59^{c}
EP	3263.00 ± 44^{a}	74409.50 ± 25^{ba}

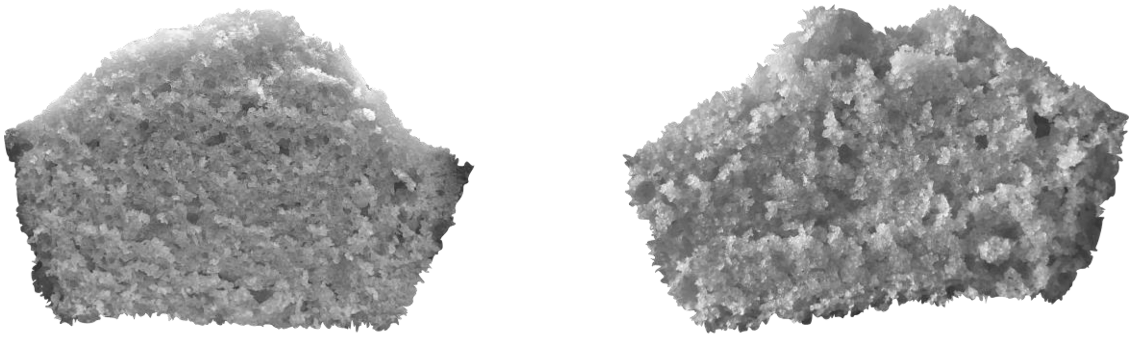
WL: Liquid egg white, WP: Egg white powder, EL: Liquid whole egg, EP: Whole egg powder. The superscript letters, in the same line, indicate that are significantly different by Duncan's multiple range test (*P*<0.05).



WL



WP



EL EP

Figure 1. Cross-sectional image of cake samples produced by liquid egg white (WL) and whole egg (EL) and powder of egg white (WP) and whole egg (EP)

CONCLUSION

This is the first to demonstrate the usability of refractance window-dried egg powders in industrial cake formulation. The results showed that most of the physical quality characteristics remained similar when egg white powder was used instead of liquid egg white. Furthermore, the physical properties of cake samples were superior when using whole egg powder compared to the liquid whole egg. The use of powdered egg led to a softer crumb texture and had a positive effect on crumb appearance.

Overall, the study suggests that refractance window-dried egg powders can be a viable alternative to liquid eggs in cake formulations, as they produce cakes with similar physical quality characteristics. However, further research is needed to optimize the use of these powders in cake formulations and to investigate their impact on other sensory characteristics of the cakes.

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CONFLICT TO INTEREST

The authors declare that there is no conflict of interest

AUTHORSHIP CONTRIBUTION

ZTA, ZEC: Investigation, Formal analysis; HCB: Data curation, Methodology, SAT: Project administration, Writing - Review & Editing.

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