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The effect of maltodextrin on properties of salted egg yolk

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ABSTRACT

Salted eggs are mainly produced through salting treatments that taste salty. However, high sodium intake is part of the pathophysiology of hypertension. Thus, this study aimed to develop low-sodium egg yolks with salting treatment using sodium chloride (NaCl) and maltodextrin to reduce salt content in the salting process. Salted egg yolks were produced using methods in the salting process using maltodextrin (10% and 20% supplement) and were compared to salted eggs brined with 20 and 26% sodium chloride (NaCl) solutions. The moisture content, salt content, color, and texture properties of salted egg yolks during salting for up to 35 days were determined. Nevertheless, salted egg yolks produced with the salting solution using maltodextrin supplement had a significant salt content (0.21-3.30 mg/g) that was lower than the amount discovered in commercial salted yolks (2.84-4.15 mg/g). The results revealed that the maltodextrin substitution affected the salted yolks' properties. The salt contents of all salted egg yolk samples gradually increased during the salting process, along with slight decreases in moisture content as salting time and salt solution concentration increased. The lightness (L*) and the yellowness (b*) decreased while the redness (a*) increased. The hardness, adhesiveness, cohesiveness, gumminess, and chewiness of salted egg yolks increased rapidly over the time of salting, while springiness decreased during the initial stages of salting and reached almost constant levels at the end of salting. As the salting time increased to 35 days, the salted yolk gradually became dark reddish. The maximum denaturation temperature (T_{max}) and denaturation enthalpy (ΔH) of egg proteins increased with increasing salting time. These effects were most pronounced due to the high maltodextrin content of the salting solution. This study suggests that this approach with maltodextrin substitution using the shell egg salting protocol can produce low-sodium salted eggs.

Keywords: Salted egg, Salting method, Egg yolk, Maltodextrin, Sodium chloride

INTRODUCTION

Factors that are physical, chemical, or microbial can harm eggs. Turning eggs into salted egg products is a popular one that is quick, inexpensive, straightforward, and capable of maintaining the nutritional content of eggs [1]. Salted eggs are egg preservation products that contain high levels of unsaturated fatty acids, fat, protein, and minerals and lower phospholipid and cholesterol levels than fresh eggs. All ages can consume them [2, 3]. Making salted eggs mainly involves soaking the eggs in a sodium chloride solution, which imparts a salty flavor and acts as a preservative. However, consuming more salt is a pathophysiologic component of hypertension. Consumption of salt was positively linked with the prevalence of hypertension and the risk of stroke [4]. Many research teams have attempted to produce low-salt salted egg yolks by using a variety of osmotic agents, including maltodextrin, glucose, potassium chloride, sodium chloride, and sucrose [5-7]. In order to lower the salted eggs' sodium content, [1] manufactured salted eggs using a salt paste containing potassium chloride (KCl) as a salt substitute. Although the salted eggs lacked interior sensory properties, their antioxidant potency was equivalent to those without KCl replacement. Using separated chicken egg yolks, [6] also employed osmotic agents to salt egg yolks with a combination of sodium chloride, potassium chloride, and sucrose. Nonetheless, salted egg yolks had a significant salt content close to the highest amount discovered in commercial salted yolks (about 2.84-4.15 mg/g). They resulted from the fact that sugar diffusion through the yolks was significantly slower than that of salt due to sugar's higher molecular weight and the fact that the majority of the sugar remained on the yolk surface [6]. Maltodextrin is a high molecular weight solute. Khin MM, et al. [8] reported that maltodextrin was used as the coating material before osmotic dehydration in fresh apples to control solute uptake. The maltodextrin coating provided an excellent barrier

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to mass transfers during osmotic dehydration. The results showed that both solute uptake and moisture loss were reduced. A few studies have attempted to add maltodextrin to the osmotic solution to control the incorporation of low molecular weight solutes, such as in the fruit tissues for pickled fruits, with the osmotic dehydration process. This idea was suggested by Azuara E, et al. [5] as a way to lower the amount of salt in salted yolks [7]. This work used the maltodextrin-salt OD system for separating salted duck egg yolk to demonstrate a novel concept of salted yolk processing. The egg yolk became watery and did not develop the desired features, even though this procedure reduced the salting period from 4 weeks to 4 days with salted content, which is equivalent to the result seen using the conventional method employing NaCl.

To address these concerns, salted egg yolks created using the traditional salting method with 20 and 26% sodium chloride solutions and fresh duck eggs made using the shell-salting procedure with a mixture solution of 20% sodium chloride and 10-20% maltodextrin were compared. A thorough understanding of the product's qualities, which has not been publicized, should also be examined. This study aimed to make low-sodium salted egg yolks with salt and maltodextrin, examine their physicochemical properties, and compare low-sodium salted yolks to standard salted yolks.

MATERIALS AND METHODS

The study was conducted at the Department of Food Science and Technology laboratory, Faculty of Home Economics Technology, Rajamangala University of Technology Phra Nakhon, located in Bangkok, Thailand. The research used a completely randomized design (CRD) with three replicates. Fresh duck eggs were acquired at a local market in Bangkok's Dusit district.

1. Chemicals

Sodium chloride (NaCl) was obtained from a local supermarket. Maltodextrin (DE 10-20) was purchased from Zhucheng Dongxiao Biotechnology Co., Ltd. (Shandong, China). Ammonium ferric sulfate ($NH_4Fe(SO_4)_2 \cdot 12H_2O$), Potassium thiocyanate (KSCN), silver nitrate ($AgNO_3$), and nitric acid (HNO_3) were obtained from were supplied by Sigma-Aldrich (Sigma-Aldrich, Co., Ltd., USA). Petroleum ether was purchased from Lab-scan (Bangkok, Thailand). Unless indicated otherwise, the chemicals were analytical grade. To compare the effect of different salting processes. The salting solution consisting of 20% NaCl, saturated NaCl solution (26% NaCl), and 20% NaCl with 10% and 20% maltodextrin were prepared.

2. Salted egg preparation

Duck eggs weighing 65-75 g and an age of less than three days were procured at a local marketplace in the Dusit district of Bangkok, Thailand. Before immersion in salting solutions consisting of 26% salt (mass fraction) and 20% NaCl, supplemented with 10% and 20% maltodextrin, the eggs underwent a cleansing process using running tap water. A thorough inspection was conducted to identify any potential fractures in the eggshell. This treatment regimen was carried out at room temperature and repeated every week for up to 35 days as part of the pickling process. A salt solution was prepared with a weight-to-weight ratio of around 1:3 concerning eggs. A total of six eggs were selected every week for salting. The egg whites and yolks were effectively segregated. A total of ten raw egg yolks were manually isolated and combined to form composite samples for each treatment. The samples were evaluated and analyzed at 7, 14, 21, 28, and 35 days after the salting process. Before instrumental identification, the samples were stored at a temperature of 4 °C in a refrigerator and packed with preservative film.

3. Determination of moisture and NaCl contents of salted egg yolks

The moisture and sodium chloride contents of salted duck egg yolk samples were analyzed using the AOAC (2000) methodology. To assess the moisture content, egg yolk samples weighing between 2.5 and 3.0 grams were evenly dispersed into weighing vials measuring 30 mm x 50 mm. These samples were then dried in a drying oven at a temperature of 105 °C until a constant weight was achieved. The following is the methodology for determining the presence of sodium chloride (NaCl): A total of 5 grams of egg yolk samples were subjected to a solution containing 20 milliliters of silver nitrate ($AgNO_3$) with a concentration of 0.1 moles per liter, along with 10 milliliters of nitric acid (HNO_3) with a concentration of 30 milliliters per 100 milliliters. Except for $AgCl_2$, the mixtures were heated slowly on a hot plate until all solids were dissolved entirely. Subsequently, a volume of 5 mL of a solution containing 5 g of $FeNH_4(SO_4)2 \cdot 12H_2O$ per 100 g of solution was introduced into the mixture when it had reached a temperature of around 24–26 °C. Once the solution exhibited a consistent light brown color, the mixtures were titrated using a standardized KSCN solution with a concentration of 0.1 mol/L. The equation employed for the calculation of the sodium chloride (NaCl) % in the given samples was as follows:

$$\text{NaCl content (\%)} = \frac{5.8\times[(V_1\times N_1)-(V_2\times N_2)]}{W} \quad (1)$$

Where;
V_1 = Volume of $AgNO_3$ solution (mL)
N_1 = Concentration of $AgNO_3$ solution (mol/L)
V_2 = Consumed volume of KSCN solution (mL)
N_2 = Concentration of KSCN solution (mol/L)
W = Weight of the salted egg yolk sample

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4. Determination of Fat contents of salted egg yolks

The Soxhlet extraction technique was employed to determine the lipid content of salted egg yolks. The experiment utilized a SoxtecTM 2055 extraction device manufactured by FOSS Analytical Solutions Pty Ltd. in Victoria, Australia. A total of 2.0 g of salted yolk samples were subjected to extraction for 60 minutes. This extraction process was conducted in individual weighing extraction flasks containing 85 mL of petroleum ether (FOSS 2055). In order to ensure complete removal of any residual solvent, the residue was subjected to an additional 20-minute period of evaporation, followed by heating at 105 °C in a hot air oven for 30 minutes. The determination of crude fat content was performed by applying equation (2) and, after that, expressing it as a percentage of the initial weight of the fresh (wet) sample, considering the variation in sample weight before and after the extraction process.

$$\text{Fat content (\%)} = \frac{(F\text{-}T)}{S} \times 100 \qquad (2)$$

Where;
F = Weight of extraction flasks and fat residues (g)
T = Weight of empty extraction flasks (g)
S = Test portion weight (g)

5. Color of salted egg yolk

According to the operation manual, the Chroma Mater CR-400 (Konica Minolta Sensing, Inc., Tokyo, Japan) analyzed the color of raw salted egg yolks nearby. All measurements were recorded six times at room temperature, and the values of lightness (L*), redness (a*), and yellowness (b*) were obtained [9].

6. Determination of texture profile analysis (TPA) of salted egg yolk

The TPA procedure was conducted using a TA-XT Plus texture analyzer manufactured by Stable MicroSystems in Surrey, England, following the methodology outlined in the reference [10]. The salted egg yolks were sliced into pieces measuring 2.0x2.0x2.0 mm. The prepared samples underwent two rounds of compression at a strain of 50% using a cylindrical aluminum probe with a diameter of 50.0 mm. The speeds recorded for the pre-test, test, and post-test were 5.0 mm/s, 1.0 mm/s, and 5.0 mm/s, respectively. The interval between two compression cycles was established as 5.0 seconds. The force-distance deformation curves were measured at a cross-head speed of 5.0 mm/s. Various parameters were obtained: hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness. The texture analysis for each treatment was repeated five times.

7. Differential scanning calorimetry analysis

Differential scanning calorimetry (DSC) TA instrument model Q20 was used to determine what happened to the proteins in salted egg yolk when the temperature changed. 5-10 mg of the sample was placed in the DSC hermetic pans. An empty hermetic pan was used as a reference sample. The samples were scanned at 10 °C per minute over the 20–120 °C temperature range. The denaturation temperature (T_{max}) was measured, and the denaturation enthalpy (ΔH) was estimated by measuring the area under the DSC transitions curve using TA analysis software.

8. Statistical analysis

The data were presented as the mean ± standard deviation of triplicate determinations. A one-way analysis of variance (ANOVA) was done, and Duncan's multiple-range tests were used to compare the means. The statistical tool (SPSS 26.0 for Windows, SPSS Inc., Chicago, IL, USA) was used to measure the statistical analyses. The significance of differences was defined at $p \leq 0.05$. The differences among treatments were verified by their least significant difference.

RESULTS AND DISCUSSIONS

1. Changes in moisture and NaCl contents of salted egg yolks

Because the inside and outside of an egg have different amounts of sodium ions (Na^+) and osmotic pressures, the Na^+ slowly goes from the eggshell to the egg white and then to the egg yolk during the salting process. The water molecules in the yolk move through the membrane into the egg white, and the water molecules in the egg white move through the membrane of the eggshell into the salting solution [11]. Figure 1 shows the changes in the amount of water and NaCl. The amount of water in egg yolks decreased as salting time and salt concentration increased. Figure 1A showed that salted egg yolks with maltodextrin salt replacement had less water than those without salt replacement ($p \leq 0.05$). Because egg white and egg yolk have different amounts of osmotic pressure, pickling made the food less liquid. The water moved from the egg yolk to the egg white and from the egg shell into the surroundings. When maltodextrin was used to replace salt in salted yolks, the water went down more than when maltodextrin was not used. Also, osmotic dehydration was higher when the amount of maltodextrin was higher. In addition, Shinde B, et al. [12] suggested that the sucrose and maltodextrin 10DE solution produced higher moisture loss than sucrose, which is composed of a comparatively lower molecular solute. A similar finding was found by Wang TH [7], who observed that when maltodextrin was added to the salting solution, the moisture in a salted yolk sample went down faster.

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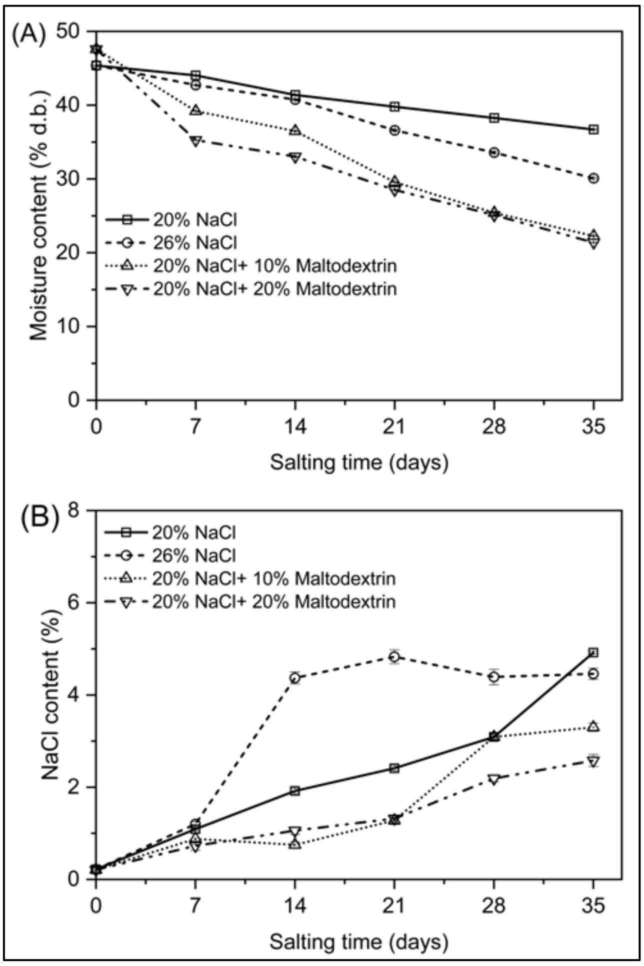

Figure 1 Change in moisture content (A) and NaCl content (B) of salted egg yolks with different salting solutions during 35 days of salting Bars represent the standard deviation from a triplicate determination.

NaCl moved from the salt solution through the eggshell in the white egg during salting. This was because the egg white's osmotic pressure increased, making it easier for the salt to keep penetrating into the egg yolk. At the same time, both the egg white and the egg yolk lost water. Both the absorption of NaCl and the loss of water would cause the yolk to harden [13, 14]. Figure 1B shows that the amount of salt in egg yolks went up significantly ($p \leq 0.05$) as the salting time (7-35 days) and the amount of salt in the salting solution went up. The salt content went up as the salting time went on, but the growth rate slowed as the salting time went on. The salt content of the salted yolks brined in a 26% NaCl solution kept rising and hitting its highest point after 21 days. This shows that the salt content of the yolks salted with maltodextrin substitution changed less quickly than that of the yolks salted in the NaCl solution. Wang TH [7], Ai MM, et al. [10], Xu L, et al. [15] and Xu L [16], have all reported results that are similar to this one. NaCl moves quickly into the egg at the beginning of salting because there is a big difference in osmotic pressure between the salting solution and the egg. Over time, the solidification of the upper yolk during the pickling process will stop some NaCl from moving into the yolk [17]. This behavior can also be explained by the combination of low molecular weight solute and high molecular weight maltodextrin, which can create a solid barrier at the surface, preventing solid gain and ultimately increasing the osmotic potential and water transfer coefficient. This also makes solids mass transfer more difficult [5, 18].

Also, yolk has a lot of oil, and the barrier of the yolk membrane can slow the movement of NaCl into the yolk. This keeps the amount of NaCl in the yolk almost the same at the end of the salting process [19]. Azuara E, et al. [5] said that the maltodextrin molecules were too big to get through the membrane. This made the salt move through the membrane more slowly. Because of this, the amount of salt in salted yolks with maltodextrin replacement went up slowly, while the amount in salted yolks in salt solution went up quickly.

In addition, yolk has a high oil content, and the barrier of the yolk membrane can slow the movement of NaCl into the yolk. This keeps the amount of NaCl in the yolk almost the same at the end of the salting process [20]. Wang TH [7] said that the maltodextrin molecules were too big to get through the membrane. This made the salt move through the membrane more slowly. Because of this, the amount of salt in salted yolks with maltodextrin replacement went up slowly, while the amount in salted yolks in salt solution went up rapidly.

2. Change in fat content of salted egg yolks

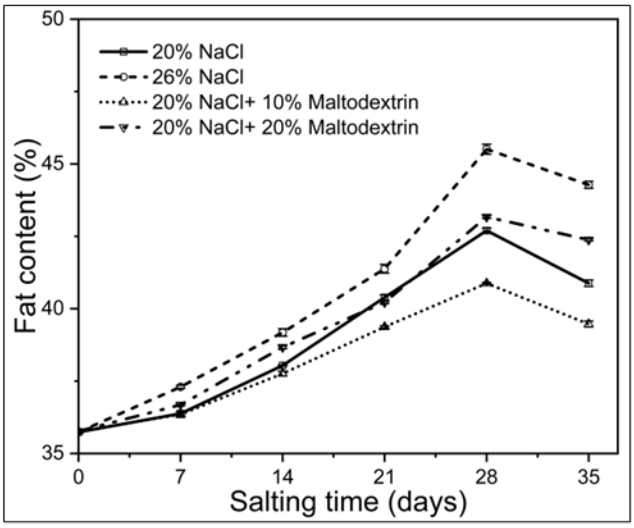

Figure 2 Change in fat content of salted egg yolks with different salting solutions during 35 days of salting. Bars represent the standard deviation from triplicate determination.

Egg yolk is rich in protein and contains a high content of lipids. The fat concentration in eggs was found to be mostly located in the yolk, reaching up to 35% [21]. During seven consecutive days, the

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yolk's exterior underwent a solidification process, but the interior retained its liquid state. Salting egg yolks primarily results in the hardening of the yolks due to reduced moisture content. The lipid content of salted egg yolks exhibited a modest increase with prolonged salting duration, primarily attributed to osmotic dehydration inside the yolk. This process led to the development of a rigid layer. According to the findings of Suretno N, et al. [22], fat extraction from egg yolk rose upon water removal.

The salting procedure induces a chemical reaction between low-density lipoprotein (LDL), the primary lipid component found in the yolk, and the salting solution. As a result of structural modifications induced by dehydration and exposure to a hypertonic environment, low-density lipoprotein (LDL) micelles undergo the release of their lipid constituents. According to previous research, it was found that the lipid content in the yolk increased from 8.5% to 16.5% over up to 14 days during the salting process [23]. According to Figure 2, the fat content of salted yolks, created using a combination of 20% NaCl and 20% maltodextrin, exhibits the greatest value, reaching 42.38% after the salting process. This finding suggests that the dehydrating effects of NaCl and maltodextrin contribute to the loss of water in the yolk, leading to an increase in oil extraction and free lipids release. These effects are mostly attributed to the structural modifications in low-density lipoproteins (LDL) during salting [15].

3. Change in color of salted egg yolks

The color data about egg yolks, as presented in Table 1, indicated a slight increase in both lightness (L^*) and yellowness (b^*) across all samples throughout a pickling period of 35 days in 20% and 26% NaCl, whereas steady decline trends of L^* and b^* for salted yolks salting in a mixture of 20% NaCl and 10-20% maltodextrin was observed. The observed alteration in color could be attributed to the desiccation experienced by the egg yolks throughout the pickling procedure.

The yellow color of egg yolks is influenced by the concentration of pigments, specifically xanthophyll and zeaxanthin [17, 24] and has been influenced by the concentration of pigments. The study of Wang X, et al. [9] suggested that the observed rise in redness could be attributed to the release of lutein and zeaxanthin, which are contained inside lipids [23]. The egg yolk subjected to prolonged storage under low moisture exhibited a noticeable deepening in its golden color.

Table 1 Color measurements of salted egg yolks during salting.

Salting solution	Salting time (days)	Color		
		L^*	A^*	B^*
20% NaCl	7	30.77^{ghij}±1.13	9.87^{h}±1.72	5.75^{fgh}±1.82
	14	29.05^{j}±0.91	12.24^{efg}±1.92	7.08^{efg}±1.46
	21	30.53^{gij}±1.91	15.17^{bc}±2.67	7.24^{efg}±1.85
	28	33.42^{def}±1.89	14.31^{bcd}±1.41	9.97^{abcd}±1.14
	35	37.20^{bc}±2.63	13.20^{cdefg}±1.98	9.0^{bcd}±1.79
26% NaCl	7	26.77^{k}±0.42	10.92^{gh}±0.66	6.09^{fg}±1.00
	14	29.49^{ij}±0.64	12.48^{defg}±1.32	7.12^{efgh}±1.14
	21	31.54^{fghi}±1.41	15.68^{b}±1.68	7.59^{ef}±1.09
	28	35.26^{bcd}±2.36	14.88^{bcde}±1.87	11.15^{b}±1.77
	35	39.95^{a}±1.81	14.74^{bcd}±1.82	10.65^{bc}±1.59
20% NaCl + 10% maltodextrin	7	41.56^{a}±0.92	18.81^{a}±0.61	25.56^{a}±1.64
	14	32.76^{efg}±2.17	10.81^{gh}±1.92	5.94^{efgh}±1.50
	21	30.30^{hij}±1.72	13.61^{bcdef}±1.56	7.82^{de}±2.14
	28	37.48^{b}±2.18	14.26^{h}±1.07	8.48^{i}±1.74
	35	33.24^{def}±2.07	14.13^{bcde}±1.53	10.25^{bc}±1.34
20% NaCl + 20% maltodextrin	7	42.12^{a}±0.80	19.09^{a}±0.61	26.31^{a}±1.43
	14	32.12^{fgh}±2.31	11.09^{gh}±1.78	3.97^{hi}±1.60
	21	30.45^{ghij}±2.07	12.94^{cdefg}±1.49	7.31^{efg}±1.66
	28	36.16±2.19^{bc}	13.32^{fgh}±1.10	7.15^{ghi}±1.40
	35	34.92^{cde}±1.90	13.76^{bcde}±1.02	8.67^{cde}±1.56

Measurements were made six times for each sampling group.
Different lower-case letters (a-g) in the same column indicate significant differences ($p \leq 0.05$).

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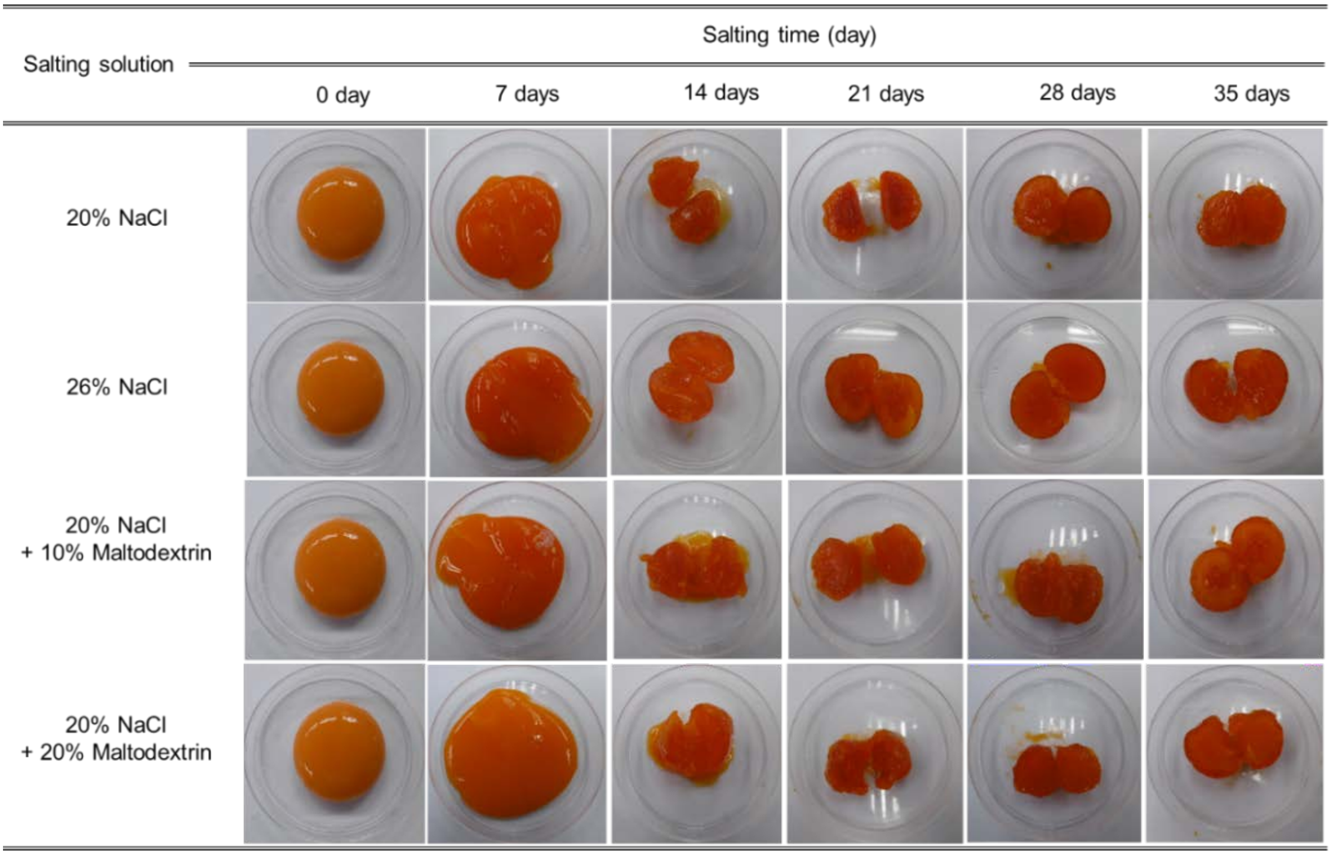

Figure 3 Appearance of salted eggs with different salting solutions during 35 days of salting.

The observed phenomenon can be attributed to the extraction of moisture, disruption of the emulsion of salted egg yolk, and the release of oil [23], which was mitigated to a lesser extent by incorporating maltodextrin. The findings are presented in reference [17]. This observation implies that the orange hue of salted egg yolk could be attributed to the heightened concentration of pigments. Consequently, the desiccation of egg yolks in the course of the salting procedure exerted an influence on both the consistency and pigmentation of the salted yolk derivative.

Figure 3 illustrates the impact of salting solutions and salting time on the visual characteristics of salted egg yolk. Throughout the 5-week salting period, the salted egg yolk acquired a progressively reddish hue across all salting solutions. After 35 days of salting, the yolks subjected to various solutions exhibited a firm and dehydrated center, accompanied by a more intense pigmentation. The alteration in hue observed in salted egg yolks during the salting process may be attributed to the reduction in moisture content, which leads to a higher concentration of pigments and free lipids within the yolks [25].

4. Change in the texture of salted egg

As shown in Figure 4B, the springiness gradually decreased throughout salting. Extremely alkaline conditions lead to the yolk proteins cross-linking and may cause a tighter connection. During 28-35 days of salting, the egg yolk gel network structure is extensively formed by electrostatic interaction forces and dehydration to a constant degree, which may contribute to the stability of springiness [3].

The adhesiveness of the salted yolk increased continuously and reached its maximum at 21 days of salting (Figure 4C). Yolks salted with maltodextrin substitution at 21-35 days exhibited higher adhesiveness than those salted with NaCl only ($p \leq 0.05$). The potential connection may also involve the liberation of unbound lipids from the lipoprotein, which contributes to the increased adhesiveness of the yolk and the reinforcement of a gel-like network during the process of yolk solidification [15].

Salted egg yolks became more cohesive from 1 to 5 weeks of salting (Figure 4D). Because the proteins in egg yolks are highly charged, they may experience unfolding at high pH levels. The intramolecular repulsions and intermolecular interactions caused by those proteins would increase noticeably [3]. Moreover, salt might help such unfolded proteins interact [26, 27]. The mechanism of salt-induced aggregation of yolk proteins with NaCl addition was disclosed by Kaewmanee T, et al. [28]. When salt is added to egg suspensions, it affects the hydrophilic groups in the protein backbone and encourages protein aggregation, which could create a gel-like network due to an increase in hydrophobicity [29]. The gumminess and chewiness of salted yolks increased with longer salting times in both the NaCl salting

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and maltodextrin substitution processes (p≤0.05). The yolks salted with a maltodextrin substitution solution for 35 days exhibited increased levels of gumminess and chewiness compared to those only salted with a NaCl solution, as depicted in Figures 4D and 4E. The increased gumminess and chewiness observed in the yolks may be attributed to using maltodextrin as a substitute for salting, as it promotes dehydration. Furthermore, it has been claimed by Kaewmanee T, et al. [13] and Xu L, et al. [15] that there was an increase in the concentration of proteins or lipoproteins, leading to enhanced interactions among them.

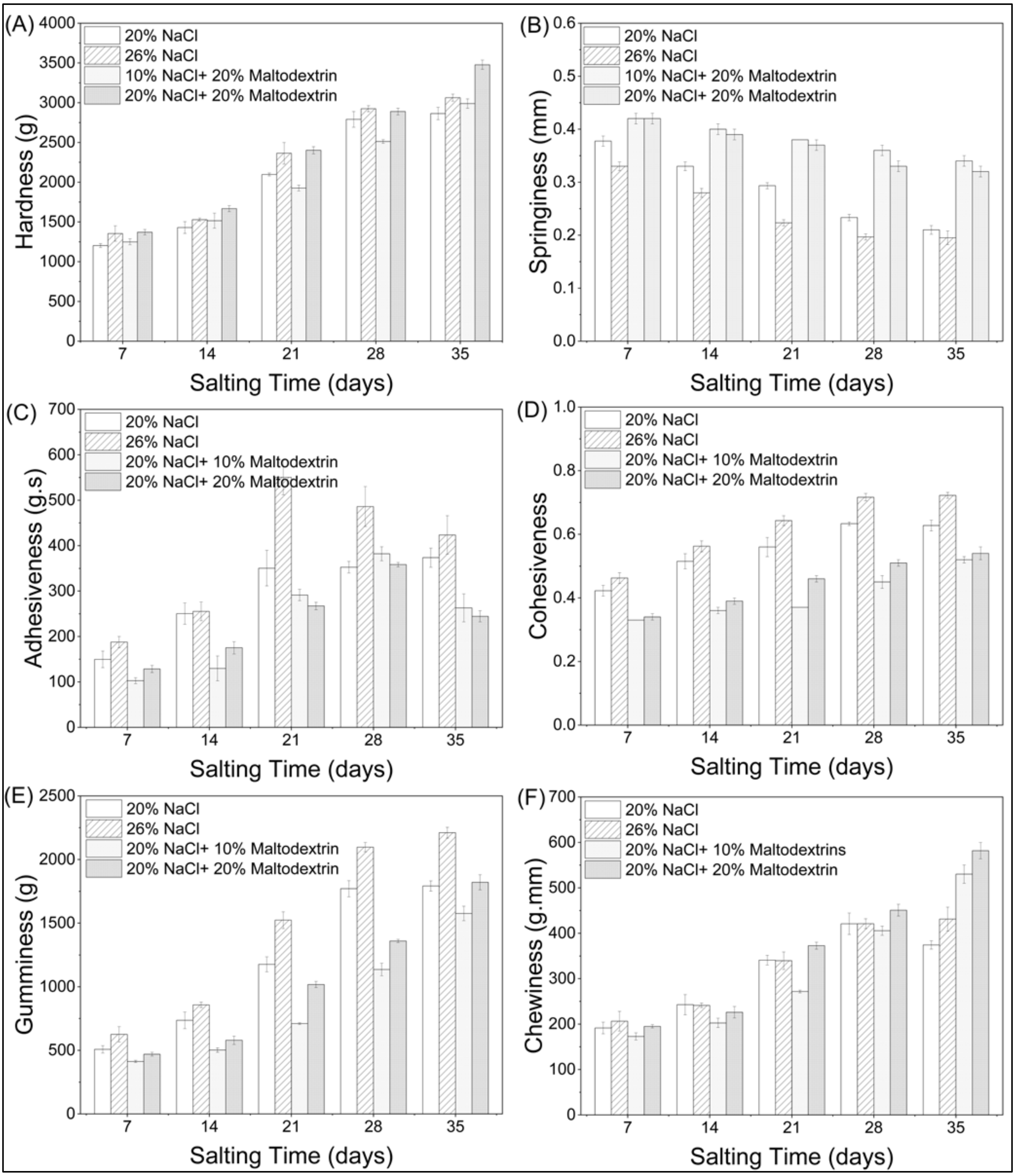

Figure 4 Texture profile analysis (hardness (A), springiness (B), adhesiveness (C), cohesiveness (D), gumminess (E), and chewiness (F) of salted egg yolks with different salting solutions during 35 days of salting Bars represent the standard deviation from six measurements.

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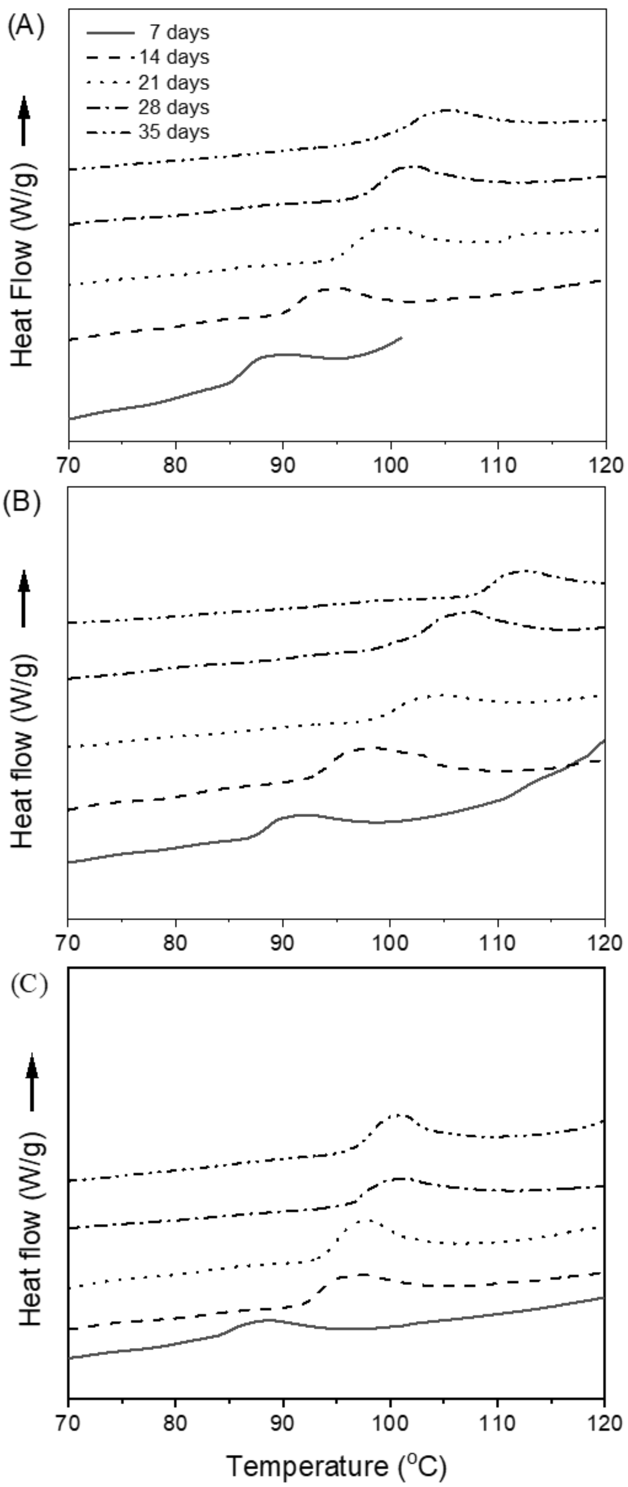

Figure 5 DSC analysis of salted egg yolk proteins during salting for 7-35 days in different salting solutions. A: 20% NaCl; B: 26% NaCl; C: a mixture of 20% NaCl and 20% maltodextrin.

5. DSC analysis of salted egg yolk proteins during the salting process

Figure 5 displayed the DSC thermogram curves, while Table 2 presented the maximum transition temperature and denaturation enthalpy of salted egg yolks. These measurements were obtained from three different samples: 20% NaCl, 26% NaCl, and a mixture of 20% NaCl and 20% maltodextrin. The salting process lasted for 7-35 days, and the DSC technique was employed to monitor the changes in the salted egg yolk proteins.

The relationship between the change in denaturation temperature and enthalpy can be attributed to the alterations in composition and conformation resulting from the salting processes [9, 20]. An endothermic peak was observed for salted yolk salting with T_{max} values of 88.07-103.85 °C for yolks salting 20% NaCl, 90.46-102.72 °C for yolks salting 26% NaCl and 88.55-100.70 °C for yolks salting the mixture of 20% NaCl and 20% maltodextrin. The thermograms of samples showed that the characteristic peak showed a significant increase with the increasing salting time. Higher T_{max} of salted yolk tended to be found with salting in 26% NaCl, particularly with longer salting durations. The observed change in denaturation temperatures aligns with the concurrent rise in salted egg yolk surface hydrophobicity during the salting process. According to the study conducted by Xu L, et al. [2], an increased presence of hydrophobic groups or proteins with a more compact structure leads to an elevated denaturation temperature. The observed phenomenon might likely be attributed to the elevated concentration of salt, which leads to a more robust network architecture and the aggregation of yolk protein under thermal conditions. A comparable pattern was documented by the study conducted by Kaewmanee T, et al. [20].

According to the data presented in Table 2 and Figure 5, including maltodextrin resulted in a modest decrease in the denaturation temperature of salted egg yolks. This decrease was observed when eggs were salted using a solution of 20% NaCl and 20% maltodextrin, compared to a solution containing only salt. According to prior research [6], it has been seen that the rate at which sugar diffuses into the yolk is comparatively slower than that of salt. This disparity can be attributed to the higher molecular weight of sugar. Additionally, it has been noted that a portion of the sugar tends to persist on the egg yolk's surface, potentially impeding salt migration into the yolk. Based on the provided explanation, maltodextrin, similar to sugar, is a solute with a high molecular weight that can impede salt absorption. Reducing salt consumption may lead to an increased prevalence of hydrophobic moieties or proteins with enhanced structural stability and a marginal decrease in denaturation temperatures. The values of denaturation enthalpy exhibited variation in response to different salting procedures and durations. The results of all treatments exhibited a positive correlation between the duration of salting and the observed rise in enthalpy.

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Table 2 The denaturation temperature (T_{max}) and enthalpy (ΔH) of salted egg yolk proteins during 35 days of salting.

Sample	Salting time (day)	T_{max} (°C)	ΔH (J.g^{-1})
20% NaCl	7	88.07^{g}±0.07	1.09^{f}±0.33
	14	94.31^{f}±1.09	1.27^{ef}±0.04
	21	99.71^{cd}±0.16	1.84^{bcd}±0.10
	28	102.29^{ab}±0.72	2.29^{ab}±0.17
	35	103.85^{a}±1.78	2.37^{a}±0.06
26% NaCl	7	90.46±1.44^{f}	1.24^{ef}±0.17
	14	97.52^{de}±0.89	1.56^{def}±0.26
	21	100.59^{bc}±1.03	2.11^{abc}±0.32
	28	101.14^{bc}±0.39	2.22^{ab}±0.01
	35	102.72^{ab}±0.25	2.37^{a}±0.01
20% NaCl + 20% maltodextrin	7	88.55^{fg}±0.49	1.34^{ef}±0.02
	14	96.64^{e}±0.04	1.67^{cde}±0.01
	21	98.84^{cde}±0.36	1.83^{bcd}±0.03
	28	100.87^{bc}±0.09	2.00^{abcd}±0.04
	35	100.70^{bc}±0.57	2.22^{ab}±0.19

Mean±S.D. from duplicate measurements.
Different lower-case letters (a-g) in the same column indicate significant differences ($p \leq 0.05$).

The salted egg yolks exhibited greater enthalpy when subjected to a combination containing 20% NaCl and 20% maltodextrin solution. The primary factor contributing to the enthalpy of protein denaturation primarily stems from the presence of alternate secondary and tertiary protein structures. Protein secondary structure is primarily influenced by hydrogen bonding, hydrophobic interactions, and ionic strength [2, 30]. On the other hand, the tertiary structure of proteins involves the aggregation of proteins and peptides in egg yolk following a salting process lasting 7-35 days. This process leads to a modification in the endothermic properties of the salted egg yolk [31]. Similar trends were reported by Kaewmanee T, et al. [20] and [2].

CONCLUSION

Characteristics of salted egg yolks were affected by salting solutions and salting time. Salted yolks obtained with the different salting solutions showed different oil content, color, transition temperature, and textural properties. The sodium level of salted egg yolks prepared using the immersing method with maltodextrin salt substitution was intended to be comparable to that of salted eggs prepared without maltodextrin substitution. Maltodextrin was used as a salt suppressant and dewatering agent. A salting solution containing 20% NaCl and 20% maltodextrin prevents over-salting of the salted yolk and produces salted egg yolks with a lower sodium content than traditional salted yolks. The physicochemical evaluation of salted egg yolks with maltodextrin substitution revealed that their overall qualities were the same as those produced with only sodium chloride treatment. This information is very useful for developing low-sodium salted eggs that hypertension patients can consume, but more bioavailability research is required to provide more comprehensive information about the health benefits of low-sodium salted eggs.

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