Development of a heatable duck egg white translucent jelly: an evaluation of its physicochemical properties and thermal stability

Nian-Yao Zheng,[*,1] Yi-Chen Chen,[*,1] Yen-Po Chen,[†,‡] Jia-Shian Shiu,[§] and Sheng-Yao Wang[*,2]

[*]*Department of Animal Science and Technology, National Taiwan University, Taipei 10617, Taiwan;* [†]*Department of Animal Science, National Chung Hsing University, Taichung 40227, Taiwan;* [‡]*The iEGG and Animal Biotechnology Center, National Chung Hsing University, Taichung 40227, Taiwan; and* [§]*Hengchun Branch, Livestock Research Institute, Council of Agriculture, Executive Yuan, Pingtung 946, Taiwan*

ABSTRACT Though nutritional, the remaining separated duck egg white in duck egg processing plants presents challenges for its transportation and use, as it spoils easily and has a strong odor. Uses for the excess egg white are of paramount concern for agricultural resource reuse. The purpose of this study was to increase its value and use efficiency. Duck egg white was mixed with sodium hydroxide to produce translucent alkali-induced egg white jelly similar to that in preserved egg whites. To develop a heatable translucent egg white jelly, their physiochemical properties and thermal stabilities were investigated. A gel prepared with 150 mM sodium hydroxide at 25°C had optimal bloom strength and the densest microstructure. Storing the jelly at 5°C helped maintain its disulfide bonds and delayed liquefaction. Although heating decreased its bloom strength and total disulfide bond content as temperature increased ($P < 0.05$), scanning electron microscopy of the heated jelly revealed that the protein network structure was denser than that of unheated jelly. Heating caused parts of the structure to shrink and even dehydrate, leading to a wrinkled surface. However, no signs of liquefaction or collapse were observed, and the free alkali released during heating was lower than that from the white of existing preserved eggs. These results confirmed the thermal stability of the jelly and its potential to be served hot or used in food processing. Furthermore, in addition to disguising the odor and special flavor attributable to the alkaline treatment, adding ginger juice or turmeric to the preparation yielded higher bloom strength, resulted in lower free alkalinity, and delayed liquefaction, thus improving the jelly's thermal stability. Like preserved eggs on the market that can be served in hot congee, the proposed egg white jelly is rich in proteins and suitable for hot or instant serving. These findings may help address the problem of excessive remaining duck egg white created during food processing by diversifying duck egg processing and boosting its value.

Key words: heatable translucent jelly, duck egg white, ginger, turmeric

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INTRODUCTION

Duck and chicken eggs are considered rich in high-quality proteins, fats, vitamins, and minerals. They are similar in their nutritional value and functional properties, with both being suitable as food or as ingredients in the food industry (Mine, 2008). However, duck eggs have a higher retail price and a unique fishy odor (Li et al., 2019). Thus, only a small portion of duck eggs are directly sold as shell eggs to household consumers, and most are processed into egg products. Regarding the processing and soaking characteristics, in comparison with chicken eggs, there are several differences between them. For example, duck egg shells contain more pores and the diameters are larger, the whites have a lower water content, and the yolks have a higher fat content, making them suitable as salted or preserved eggs (Li and Hsieh, 2014; Balkan and Biricik, 2008; Chaiyasit et al., 2019). With recent advances and breakthroughs in the processing technology for salted eggs, producers have started adopting a rapid soaking method and using the separated yolks to meet the strong demand for salted yolks (Wang, 2017). However, due to the distinct odor, restricted applications, and perishability, the remaining duck egg whites are less desirable and mostly used as fertilizer or livestock feed, or even discarded as agricultural waste. Accordingly, developing products made from duck egg whites may help address the current problem

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[1]NY Zheng and YC Chen contributed equally as co-first authors.

[2]Corresponding author: yaoyao@ntu.edu.tw

of their excess and create the potential for more diverse egg products.

Preserved eggs, which are processed duck egg products specific to Asia, are usually made by soaking the duck eggs in a solution containing substances such as sodium hydroxide (4−5%), sodium chloride (4%), and metal salts (e.g., copper sulfate, zinc sulfate, or lead oxide) at 17 to 25°C for approximately 40 d. Preserved eggs are loved by many Asian people for their unique flavor, color, and texture (Wang and Fung, 1996; Chen and Su, 2004; Tu et al., 2013). The preserved egg white is a translucent, elastic, protein-rich, jelly-like gel with a distinctly different appearance from heat-induced egg white gel. Interestingly, preserved egg whites maintain their structure and springiness even after heating by boiling or deep-frying. Recently, several researchers have become increasingly curious about the preserved egg white's springy texture, translucency, and resistance to heating, as well as its long shelf life; they have thus investigated the properties of alkali-induced egg white gels (Chen et al., 2015; Li et al., 2018; Huang et al., 2019; Ai et al., 2020b).

When egg white is exposed to a strong alkaline environment, the secondary and tertiary structure of ovalbumin (the principal protein in egg white) is damaged, consequently leading to unfolding. Then, these protein chains gradually form into aggregates and ultimately result in a stable egg white gel (Bryant and McClements, 1998; Zhao et al., 2016a). Chen et al. (2015) analyzed the formation and stabilization of alkali-induced egg white gels and verified that the process is mainly attributable to disulfide bonds and ionic bonds, followed by hydrophobic forces and hydrogen bonds. However, a continuous strong alkali treatment or an excessively high alkaline concentration gradually damages the protein network structures, and they tend to finally collapse and liquefy (Ma, 2007; Zhao et al., 2014a, 2016b). In contrast, an insufficient alkaline concentration can result in incomplete protein unfolding and thus hinder gel formation (Huang et al., 2019). In addition, Zhao et al. (2014a) have demonstrated that temperature deeply affects the formation, stability, and strength of alkali-induced gels, which is related to the rate of NaOH permeation into the egg white and reaction velocity. At higher temperatures, the gel strength rapidly increases to a peak and subsequently decreases more quickly, even leading to the collapse and liquefaction of the gels. Zhang (2004) has argued that a high soaking temperature can also damage preserved egg white and result in liquefaction, thereby causing the preserved eggs' quality to fail and the final product yield to drop. Nevertheless, in our preliminary study, when alkali-induced duck egg white gels were stored at low temperature over a day, the gel structure retained its semi-solid and intact shape after heating in boiling water. Therefore, in addition to using an appropriate sodium hydroxide concentration when preparing gels, the temperature during gel formation and subsequent preservation temperature are critical factors in stabilizing alkali-induced egg white gels.

To rapidly convert the large quantities of remaining separated duck egg whites into a stable, translucent egg white jelly that can be served in hot foods like a preserved egg white, we increased the separated duck egg white content in the jelly to 80% (w/w), adjusted the alkali concentration, and controlled the reaction temperature. We also investigated the effects of temperature on the bloom strength, appearance, and stability of the translucent egg white jelly. Besides, ginger and turmeric (*Cturmeric longa*) are spices commonly used to disguise unwanted odors in food, and mostly in Asian cuisine, to season and flavor dishes. Accordingly, we produced translucent egg white jellies containing ginger juice or turmeric and evaluated their thermal stability and organoleptic properties in hopes of developing a high-protein food ingredient with a translucent, gel-like appearance that can be served in hot foods. By developing a novel egg white jelly from excess duck egg whites, our aims were to address the problem of duck egg whites going to waste, increase diversity in duck egg processing, and boost the value of duck eggs.

MATERIALS AND METHODS

Materials

Brown Tsaiya duck eggs (*Anas platyrhynchos* var. *domestica*) were purchased from Kindly Eggs Co., Ltd. (Pingtung, Taiwan), stored at room temperature, and used within 1 wk of being laid. All other chemicals used in this study were of analytical or food grade; sodium hydroxide was purchased from Formosa Plastics Corporation (Taipei, Taiwan); both ginger juice powder and turmeric powder were purchased from Tomax Enterprise Co. Ltd. (Taipei, Taiwan).

Preparation of Egg White Jelly

Duck eggs weighing 65 to 75 g were selected for the experiment. The eggs were first cracked and poured onto a plate, the yolk was then removed with a slotted spoon, and the separated egg white was collected into a beaker for subsequent procedures. Sodium hydroxide was dissolved in deionized water to prepare sodium hydroxide solutions of varying concentrations. The separated duck egg white was then mixed with the sodium hydroxide solutions at a 4:1 ratio using an electronic overhead stirrer (Hei-TORQUE Core; Heidolph Instruments GmbH & CO. KG, Germany) at 300 rpm for 30 s. The alkali-treated duck egg white solutions were left to stand at different temperatures during the reaction to form alkali-induced duck egg white gels (also known as egg white jelly) with 80% duck egg white and varying molar concentrations of sodium hydroxide (0, 100, 125, 150, 175, and 200 mM). To prepare flavored egg white jelly, after the optimal concentration of sodium hydroxide solution was decided, ginger powder or turmeric powder was dissolved in the sodium hydroxide solution before mixing with the duck egg white to produce

translucent egg white jelly with 0.5% (w/v) ginger or turmeric.

Measurement of Viscosity Variation and Gelation Time

The variation in viscosity of the alkali-treated duck egg white solutions was measured with a rheometer (RST-CPS; Brookfield Engineering Laboratories Inc., Middleboro, MA). A consistent shear rate of $100 \cdot s^{-1}$ was achieved using a plate-plate geometry with 75 mm diameter plates (RPT-75) separated by a 1 mm gap. An alkali-treated duck egg white solution was placed on the testing plate, and the sample's viscosity was determined at a shear rate of $100 \cdot s^{-1}$. To determine the variation in viscosity, observations were made every 10 s at 25°C for alkali-treated duck egg white solutions made with 100, 125, 150, 175, and 200 mM sodium hydroxide. After determining the optimal sodium hydroxide concentration for preparing the alkali-induced egg white gels, this concentration was mixed with duck egg white at 5, 15, 25, 35, or 45°C to determine the variation in viscosity. In addition, gelation time was defined in this study as the time required for the viscosity value of the solution to reach 2 Pa·s, marking the beginning of alkali-induced egg white gel formation.

Rheological Profile Measurements

The method for obtaining the rheological profiles was modified from that of Ai et al. (2020b). To determine the effect of temperature on the samples' elastic modulus and viscous modulus values, we used a stress-controlled rheometer (AR2000ex, TA Instruments, New Castle, DE) fitted with a 40-mm steel parallel plate was used to conduct the rheological variation analysis of the alkaline egg white solutions while forming gels. First, 20 mL of duck egg white was mixed with 5 mL of a sodium hydroxide solution, immediately after which a sample of the mixture was loaded onto the rheometer and monitored for 900 s in an oscillatory regime with a frequency of 1 Hz and a strain of 1.0%.

Measuring Gel Strength

A TA-XT Plus Texture Analyzer (Stable Micro System Ltd., Godalming, UK) was employed to analyze the gel strength with a 5 kg load cell and a radius cylinder probe (P/0.5, $\Phi^1/_2$", Derlin). An egg white jelly sample with a 3.5 cm diameter and 5.0 cm height (in a glass container) was compressed by the probe to a target distance (15.0 mm) with a 1.5 $mm \cdot s^{-1}$ pre-test speed, 1.0 $mm \cdot s^{-1}$ test speed, 1.0 $mm \cdot s^{-1}$ post-test speed, and a 5 g trigger force. The analysis was performed with 3 replicates of each independent batch. The force was expressed as the resistance to penetration, which was then converted into bloom strength (g). For the thermal stability testing, the egg white jelly was stored at 5°C for 24 h, after which it was placed in a constant-temperature water bath at 60, 70, 80, 90, or 100°C for 10 min, removed from the water bath, and allowed to cool till the room temperature before subsequent tests.

Scanning Electron Microscopy

As described by Ai et al. (2020b), scanning electron microscopy (**SEM**) was used to observe the microstructure of the egg white jelly. The jelly sample was cut into cubes (2 × 2 × 2 mm) and fixed in a protein immobilization solution (0.1 M phosphate-buffered saline [**PBS**] with 2.5% glutaraldehyde) for 24 h. Subsequently, the protein immobilization solution was removed, and the sample was rinsed thrice for 10 min with 0.1 M PBS. After suctioning out the final PBS rinse, the sample was then dehydrated with an ethanol gradient, which began by soaking twice in 35% ethanol (Sigma-Aldrich Co., LLC., St. Louis, MO) for 10 min at room temperature, with the 35% ethanol exchanged between soaks. Similarly, the sample was soaked twice each for 10 min in increasing concentrations of ethanol (50, 60, 70, 85, 90, and 95%). The sample was then washed thrice with 100% ethanol and dried in a critical point dryer (Samdri®-PVT-3B; Tousimis Co., Inc., Rockville, MD). Finally, the sample was covered with gold using an ion sputter (SPI, West Chester, PA) and observed by SEM (JSM 6510 LV; JEOL, Tokyo, Japan) at a 10,000 × magnification.

Determination of Free Thiol Group, Total Thiol Group, and Disulfide Bond Contents

The thiol group and disulfide bond contents in the duck egg white jelly were determined according to the methods of Yarnpakdee et al. (2009) and Ai et al. (2020a). First, a mixture of samples (500 mg) and PBS solution (4.5 mL) were homogenized for 40 s (Polytron, PT-2100; VWR International LLC., Radnor, PA) and then centrifuged for 15 min at 9,170 × g (Micro Refrigerated Centrifuge Model 3700; Kubota Co., Osaka, Japan). The supernatant was collected, and the protein content was determined by the Bradford protein assay.

To determine the free thiol group, 0.1 mL of supernatant was mixed with 1.4 mL of Tris-Gly buffer (0.089 mol/L Tris, 0.09 mol/L glycine, 0.004 mol/L EDTA, pH 8.0) containing 8 mole/L urea; 0.02 mL of Ellman reagent [5, 5′-dithiobis (2-nitrobenzoic acid)] was added to the mixture, which was then placed in a 40°C circulating water bath (GDB160; Genepure Technology Co., Ltd., Taichung, Taiwan) to react for 15 min. An ELISA reader (Synergy H1 hybrid reader; Biotek Inc., Winooski, VT) was then used to measure the sample's absorbance at 412 nm.

To determine the total thiol group content, 0.02 mL of supernatant was mixed with 0.28 mL of Tris-Gly buffer (pH 8.0) that contained 1.5 mg/mL β-mercaptoethanol, 0.5% sodium dodecyl sulfate, and 8 mol/L urea; the mixture was placed in a 40°C water bath to react for 60 min.

One milliliter of 12% (w/v) trichloroacetic acid (**TCA**; J. T. Baker Inc., Dallas, PA) was then added to the mixture, which was allowed to react for another 60 min before centrifuging at 4,000 × *g* for 10 min. The precipitated proteins were collected and washed thrice with 12% (w/v) TCA and then dissolved in one mL of Tris-Gly buffer (pH 8.0) containing 8 mole/L urea; 0.8 mL of the solution was added to 4 μL of Ellman reagent, and the reaction was placed in a 40°C water bath for 15 min before transferring 0.2 mL to a 96-well plate to determine the absorbance at 412 nm. The same buffer without a sample was employed for the blanks. All the aforementioned tests were performed in triplicate, and the absorbance coefficient was 13,600·M^{-1}·cm^{-1}. The free thiol group, total thiol group, and disulfide bond contents were calculated as follows:

$$SH(\mu mol/g\ protein) = A_{412} \times\ 73.53\ \times D/C$$

$$SS(\mu mol/g\ protein) = (SH_T - SH_F)/2,$$

where A_{412} is the sample's absorbance at 412 nm, D is the sample dilution factor, C is the protein concentration, SH_T is the total thiol group content, and SH_F is the free thiol group content.

Color Parameters

Following the color determination method of Croguennec et al. (2002), the color parameters of the egg white jelly samples obtained from the different heat treatments were measured using a color checker (NR-11; Nippon Denshoku, Bunkyo, Tokyo, Japan). The L*, a*, and b*values indicate lightness, redness, and yellowness, respectively. The prepared egg white jelly was stored at 5°C for 24 h and then placed in a water bath at 60, 70, 80, 90, or 100°C for 10 min. The heat-treated samples were cooled to 25°C and cut with a knife into 1-cm-thick cylinders. After a black and white calibration, the gel surface was directly measured using the color checker for L*, a*, and b*.

Determining the Free Alkalinity

The free alkalinity of the egg white jelly was determined as described by Ai et al. (2020a). A 30 g sample with a contact area of approximately 5,024 mm^2 was placed in a capped glass bottle and 25 mL of deionized water was added; the bottle was then heated in a water bath at 60, 70, 80, 90, or 100°C for 10 min. The 25 mL of supernatant was collected from the bottle and titrated using 0.1 M hydrochloric acid and a pH meter (C833 multichannel analyzer; Consort bvba, Turnhout, Belgium) to determine the pH values, with the titration ending when pH 7.0 was reached. The volume of hydrochloric acid consumed was recorded and used for the free alkalinity calculation with the following equation:

$$Free\ alkalinity\ (mg/100\ g) = C \times V \times 40 \times 100/m,$$

where C is the concentration of hydrochloric acid (M), V is the volume of hydrochloric acid consumed in the titration, 40 is the molecular mass of sodium hydroxide consumed with 1 mL of 1 M hydrochloric acid, 100 is the conversion coefficient, and m is the sample weight (g).

Organoleptic Evaluation

An organoleptic evaluation was conducted by performing a hedonic scale test on 10 g of egg white jelly (25°C) from each treated sample. The evaluation was conducted by 50 panelists comprised of students and faculty members in the Department of Animal Science and Technology at the National Taiwan University. The evaluation considered the appearance, aroma, texture, flavor, and total acceptability on a 9-point hedonic scale (9 = likes extremely; 8 = very much likes; 7 = moderately likes; 6 = somewhat likes; 5 = neither likes nor dislikes; 4 = slightly dislikes; 3 = moderately dislikes; 2 = very much dislikes; and 1 = extremely dislikes). The sensory evaluation of the egg white jelly was conducted at 25°C after heating the samples to 80°C for 10 min. All evaluations were performed at room temperature.

Statistical Analysis

All testing parameters were measured at least 3 times in each batch and subjected to one-way ANOVA. When a significant difference ($P < 0.05$) was detected among groups, significant differences between treatments were further determined at the 0.05 probability level ($P < 0.05$) by the least significant difference (**LSD**) test.

RESULTS AND DISCUSSION

Effects of Sodium Hydroxide Concentration and Reaction Temperature on the Time Required for Duck Egg White Gel Formation

In the preliminary test, duck egg white and sodium hydroxide solution were evenly mixed, and the viscosity was determined at a shear rate of 100·s^{-1}. The viscosity of the alkali-treated duck egg white solution grew gradually until 2 Pa·s was reached when the solution began losing its liquidity and began turning into a gel. Therefore, in this study, the gelation time was defined as the time required for the viscosity of the duck egg white solution to reach 2 Pa·s. Table 1 presents the results of the viscosity assay of the alkali-treated duck egg white solutions. The solution containing 100 mM sodium hydroxide increased in viscosity during the first 30 min, but stopped at 1.8 Pa·s without forming a gel. By contrast, when the sodium hydroxide concentration in the duck egg white solution was increased to 125 mM, the viscosity increased to 2 Pa·s within 15 min, and an alkali-induced egg white gel was formed. The egg white solutions quickly (within 5 min) transformed into gels when the concentration of sodium hydroxide was increased to 150, 175, or 200 mM. Thus, the concentration of sodium hydroxide played a critical role in the time required for an alkali-induced egg white gel to

Table 1. Changes in viscosity (Pa·s) of alkali-treated duck egg white solution containing different concentrations of sodium hydroxide at 25°C.

	NaOH concentration (mM)					
Min	0	100	125	150	175	200
0	0.020 ± 0.000^{c}	$0.022 \pm 0.002^{H,c}$	$0.027 \pm 0.009^{E,bc}$	$0.032 \pm 0.011^{B,bc}$	$0.031 \pm 0.029^{B,b}$	$0.070 \pm 0.002^{B,a}$
3	0.021 ± 0.000^{c}	$0.036 \pm 0.019^{G,c}$	$0.149 \pm 0.051^{D,b}$	$2.281 \pm 0.436^{A,a}$	$2.520 \pm 0.347^{A,a}$	$2.431 \pm 0.455^{A,a}$
6	0.023 ± 0.011^{c}	$0.052 \pm 0.008^{F,b}$	$0.589 \pm 0.049^{c,a}$	—	—	—
9	0.023 ± 0.002^{c}	$0.061 \pm 0.010^{F,b}$	$1.348 \pm 0.223^{B,a}$	—	—	—
12	0.021 ± 0.002^{c}	$0.156 \pm 0.058^{E,b}$	$1.610 \pm 0.137^{B,a}$	—	—	—
15	0.021 ± 0.000^{c}	$0.302 \pm 0.087^{D,b}$	$2.443 \pm 0.108^{A,a}$	—	—	—
18	0.022 ± 0.010^{b}	$0.866 \pm 0.136^{c,a}$	—	—	—	—
21	0.024 ± 0.000^{b}	$0.846 \pm 0.076^{c,a}$	—	—	—	—
24	0.024 ± 0.000^{b}	$1.188 \pm 0.355^{B,a}$	—	—	—	—
27	0.021 ± 0.000^{b}	$1.707 \pm 0.160^{A,a}$	—	—	—	—
30	0.023 ± 0.010^{b}	$1.812 \pm 0.006^{A,a}$	—	—	—	—
33	0.021 ± 0.000^{b}	$1.815 \pm 0.025^{A,a}$	—	—	—	—
36	0.020 ± 0.000^{b}	$1.819 \pm 0.052^{A,a}$	—	—	—	—

$^{A-H}$Means in the same column without a common superscript capital letter indicate a significant difference ($P < 0.05$).
$^{a-c}$Means in the same row without a common superscript lower case letter indicate a significant difference ($P < 0.05$). *Note:* Dash (—) indicates egg white solution gelled. Data are given as the mean ± SE ($n = 3$).

form, with higher alkali concentrations resulting in faster egg white gel formation (Zhao et al., 2014a; Chen et al., 2015).

To determine the effect of reaction temperature on gelation time, an alkali-treated duck egg white solution containing 150 mM NaOH was prepared to measure the viscosity, and thus time required for gel formation, at different temperatures. As seen in the results (Figure 1A), the alkali-treated egg white solution at 5°C did not reach a viscosity of 2 Pa·s within the first 15 min, while the reactions at 25, 35, and 45°C reached a viscosity of 2 Pa·s and formed gels after 4, 2, and 1 min, respectively, demonstrating that the gel required significantly less time to form as the reaction temperature increased ($P < 0.05$). We further confirmed the effect of temperature on the gelation of the alkali-treated egg white solution by measuring its rheological properties. As shown in Figure 1B, the viscous modulus (G") increased substantially as the temperature rose. This result was consistent with that of the viscosity test, suggesting that a high reaction temperature is conducive to enhancing the viscosity of the alkali-treated egg white solution and accelerating gel formation. Li et al. (2018) also reported that the elastic modulus (G') of egg white increases as heating proceeds and plateaus when it reaches a certain level, namely when the egg white gel has formed. Figure 1C indicates that in our study, the trend of change in G' was consistent with that in G", which increased with the reaction temperature. As reaction time increased, a higher reaction temperature was found to increase the level of protein aggregation, hence increasing the viscosity and accelerating gelation.

Effect of Sodium Hydroxide Concentration on the Textural Properties and Microstructure of Alkali-Induced Duck Egg White Gels

Previous studies have demonstrated that although while an excessively high concentration of sodium hydroxide can make an egg white solution turn to gel in a short period, it also rapidly damages the network structure of the protein aggregation in the gel, leading to the collapse and liquefaction of the gel structure (Yang et al., 2012; Zhao et al., 2014a; Chen et al., 2015). To choose the appropriate alkali concentration for preparing stable alkali-induced egg white gels, alkali-treated egg white solutions containing 150, 175, and 200 mM sodium hydroxide were maintained at 25°C while forming the gels (i.e., 150 mM-EWG, 175 mM-EWG, and 200 mM-EWG) and then observed for variation in their bloom strength and whether liquefaction occurred in the standing process. The results are depicted in Figure 2A. At the beginning of gel formation (Hour 0), the 3 gels exhibited no significant difference in bloom strength ($P > 0.05$). After 0.5 h of standing at 25°C, the bloom strengths of 175 mM-EWG and 200 mM-EWG were significantly higher than that of 150 mM-EWG ($P < 0.05$). However, after one h, the bloom strength of 150 mM-EWG reached 70 g, which was significantly higher than those of the other 2 ($P < 0.05$). After 3 h, the bloom strengths of the gels with the higher alkali concentrations (175 mM-EWG and 200 mM-EWG) had reduced from above 60 g to below 40 g, and the gels' appearances exhibited noticeable signs of liquefaction (data not shown). Such signs of liquefaction were not observed in the 150 mM-EWG, whose bloom strength was little altered from the levels observed at Hours 1 and 2. Consequently, despite helping the gel reach peak bloom strength faster, the high concentrations of sodium hydroxide accelerated the damage to and liquefaction of the gel structure. By contrast, while the alkali-induced egg white gel prepared using the lower sodium hydroxide concentration reached its peak bloom strength later in the process, it had better performance in maintaining its bloom strength and structural stability.

When animal proteins such as ovalbumin, whey protein, and bovine serum albumin are subjected to heat or pH adjustments, the denatured proteins aggregate into a network structure and eventually form protein gels

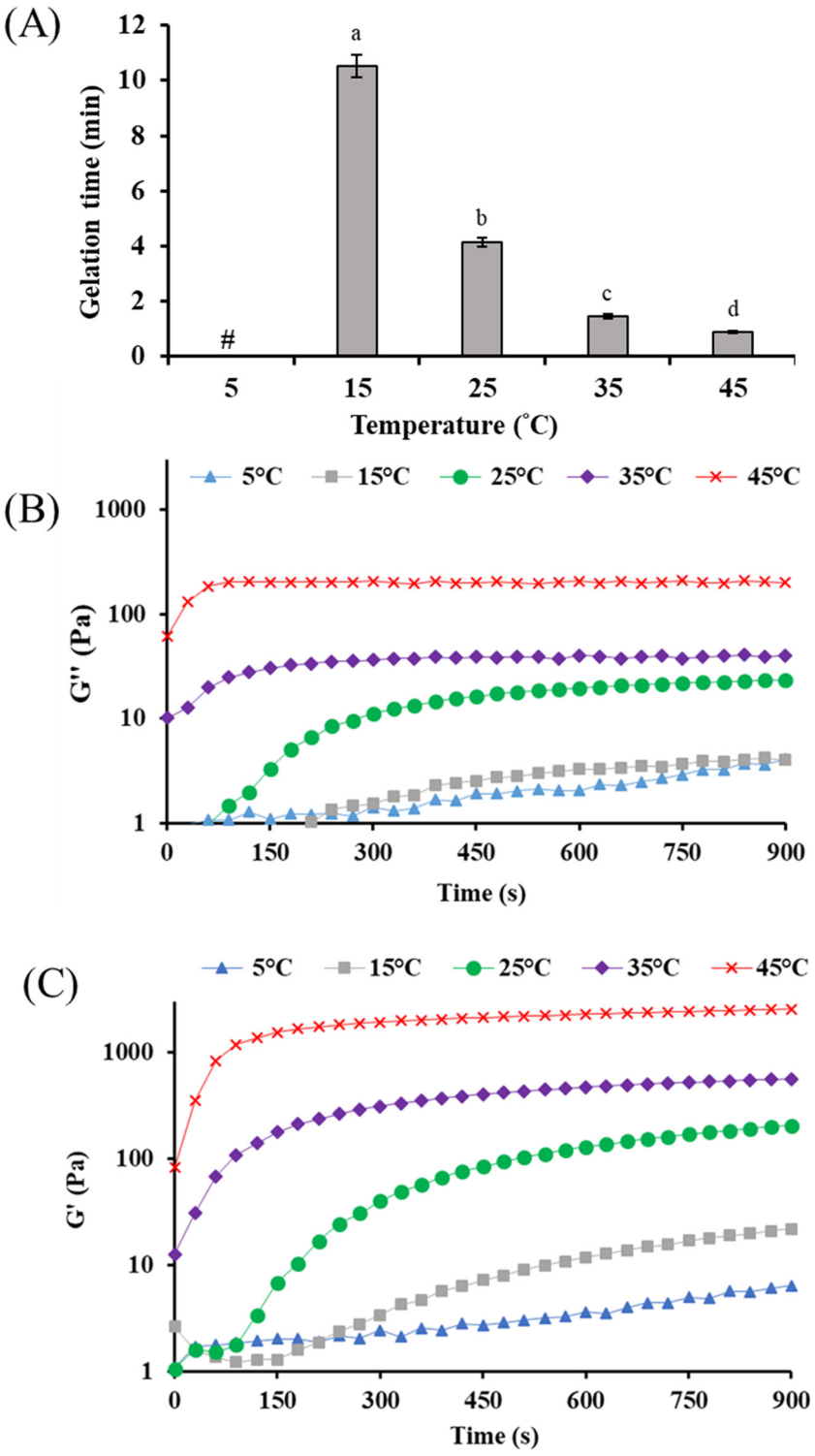

Figure 1. Effect of reaction temperature on the (A) gelation time, (B) viscous modulus (G"), and (C) elastic modulus (G') of alkali-induced duck egg white gels. Gelation time refers to the time required for the viscosity of alkali-induced duck egg white to reach 2 Pa•s. #, Viscosity of the 5°C group did not reach 2 Pa•s within 15 min. Data in (A) are given as the mean ± SE ($n = 3$). Data bars without a common letter indicate a significant difference ($P < 0.05$).

(Sagis et al., 2002; Veerman et al., 2003; Weijers et al., 2006). In addition to measuring the gel strength, SEM observations of the 3-dimensional network structure formed by protein aggregation can provide a reference for determining the integrity and density of a gel structure (Heertje, 2014). Figure 3A shows the microstructure of the alkali-induced duck egg white gels prepared using different sodium hydroxide concentrations. The gels stood at 25°C for 1 h before the SEM microstructure observations were made, which revealed protein chains of different thicknesses and branch structures of varying density. Particularly, the microstructure of 125 mM-EWG was a sparse network structure with thin protein chains. By contrast, 150 mM-EWG and 175 mM-EWG exhibited thicker protein chains and denser protein aggregation, which was probably due to the sufficient

concentration of sodium hydroxide accelerating the unfolding and denaturation of the protein molecules and facilitating the formation of a network structure. However, an excessively high sodium hydroxide concentration can result in protein hydrolysis and damage the formed gel structure (Ma, 2007; Zhao et al., 2014a). Thus, the microstructure of 200 mM-EWG exhibited relatively loose protein chains and a sparse distribution of branch structures. Because the bloom strength and dense fine structure in 150 mM-EWG were favorable, egg white solutions with 150 mM sodium hydroxide were used to prepare stable egg white gels under suitable temperatures in subsequent experiments.

Effect of Reaction Temperature on the Physiochemical Properties and Microstructure of Alkali-Induced Duck Egg White Gels

The selected 150 mM-EWG was prepared using reaction temperatures of 5, 15, 25, 35, or 45°C, with corresponding temperatures during the standing process. Figure 2B reveals that the gel had a bloom strength of 22 g when the alkali-induced duck egg white gel was prepared at 5°C and stood at that temperature for 0.5 h; this strength was significantly lower than those of the other gels ($P < 0.05$), but it increased to 50 g after 3 h. The 150 mM-EWG prepared at 15 and 25°C also exhibited an increasing trend in bloom strength with standing time. Notably, after the first hour of standing, the bloom strength of 150 mM-EWG prepared at 35°C was significantly higher than those of the others ($P < 0.05$), but it decreased thereafter. Regarding 150 mM-EWG prepared at 45°C, the bloom strength peaked at 38 g after the first hour, but decreased to less than 20 g after 3 h, thus exhibiting the least favorable bloom strength performance and liquefaction after a 3 h standing process. This result was similar to that of Zhao et al. (2014a). The separated egg white transformed into a gel after reacting with the alkali, but over time, the bloom strength gradually increased, peaked, and then decreased. Therefore, temperature affected not only the time required for gelation, but also the bloom strength and stability of the alkali-induced duck egg white gels.

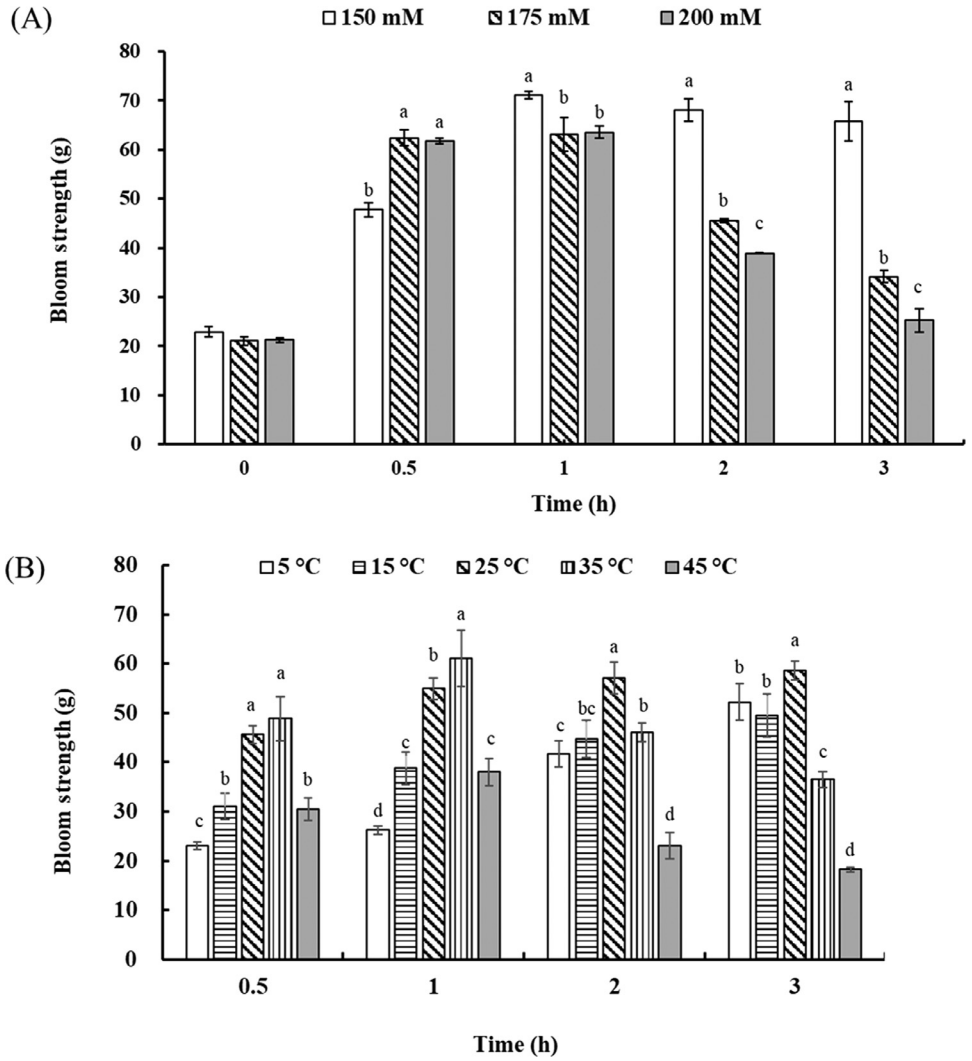

Figure 2. Changes in the bloom strength of alkali-induced duck egg white gels prepared using different (A) sodium hydroxide concentrations and (B) standing temperatures. Data are given as the mean ± SE ($n = 3$). Data bars in each period without a common letter in the same period indicate a significant difference ($P < 0.05$).

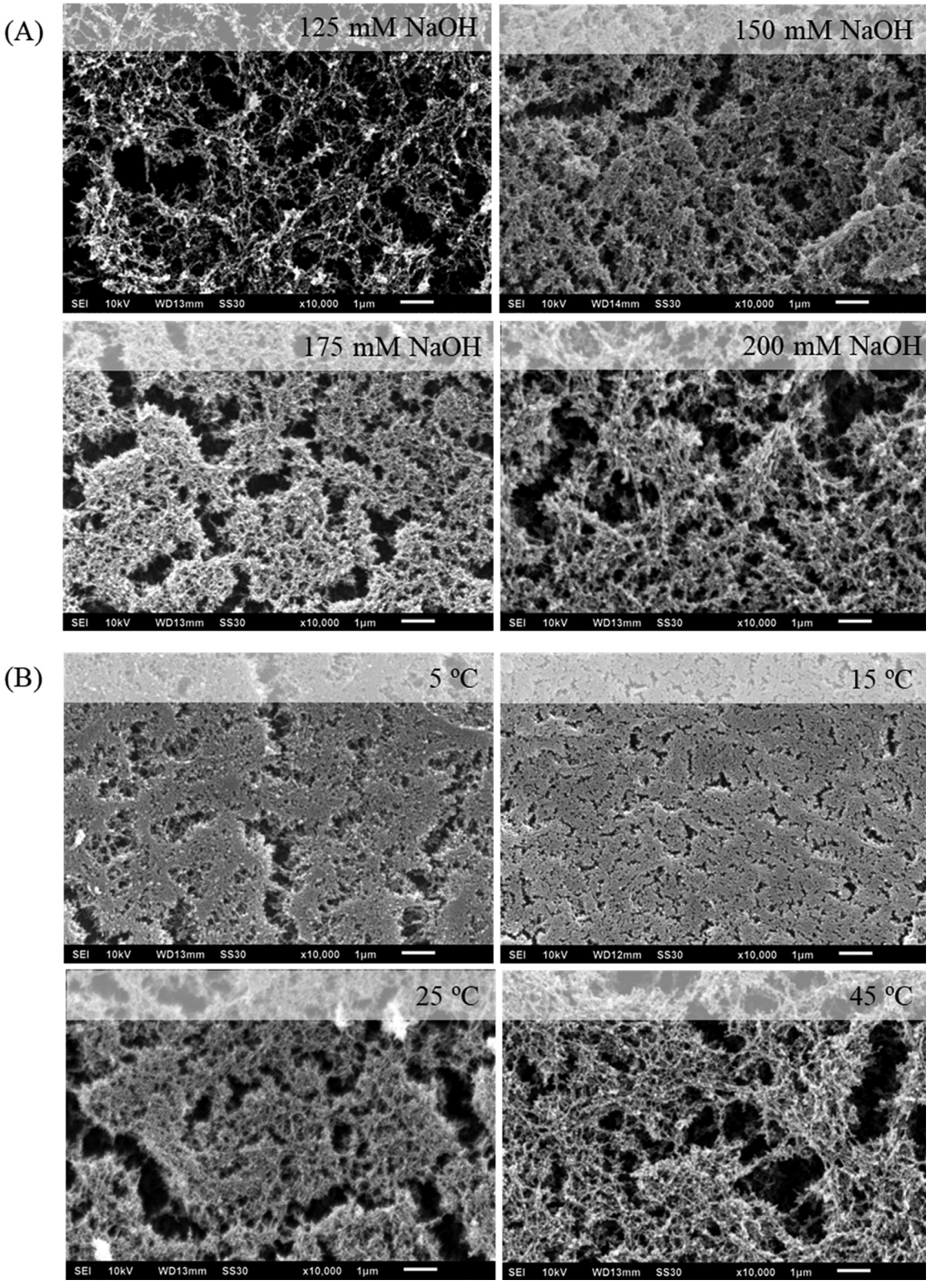

Figure 3. Scanning electron microscopy images of the microstructures of alkali-induced duck egg white gels prepared (A) using different sodium hydroxide concentrations at 25°C and (B) using 150 mM sodium hydroxide at different reaction temperatures. Magnification: 10,000 ×.

In terms of the protein structures in egg white, egg white ovalbumin and ovotransferrin have 4 free thiol groups and 15 disulfide bonds, respectively (Mine, 1995). When subjected to pH variations or heating, the free thiol groups in ovalbumin become exposed, and the disulfide bonds in ovotransferrin are cleaved, forming disulfide bonds between molecules through thiol group−disulfide bond exchanges (He et al., 2013). According to Zhao et al. (2009), this thiol-disulfide bond exchange plays a critical role in forming a gel structure, with the disulfide bonds between molecules as a crucial force in maintaining the structure of both preserved and

Table 2. Effect of reaction temperature on the total free thiol group and disulfide bond contents in alkali-induced duck egg white gels.

Parameters	Reaction temperature (°C)	Period (h)						
		0	0.5	1	2	3	4	5
Free thiol group content (μmol/g protein)	5°C	35.02 ± 0.12^{a}	20.38 ± 3.60^{c}	$26.77 \pm 3.58^{B,bc}$	$26.21 \pm 3.05^{B,bc}$	$28.02 \pm 2.15^{B,b}$	$32.34 \pm 1.17^{C,ab}$	$35.02 \pm 2.25^{C,a}$
	15°C	34.97 ± 0.21^{b}	20.38 ± 1.43^{d}	$28.16 \pm 2.65^{B,c}$	$29.15 \pm 2.70^{B,c}$	$31.64 \pm 0.70^{B,c}$	$33.36 \pm 1.86^{BC,bc}$	$37.88 \pm 0.61^{C,a}$
	25°C	36.04 ± 0.61^{b}	19.92 ± 1.90^{e}	$23.81 \pm 2.53^{B,d}$	$23.73 \pm 2.08^{BC,d}$	$32.05 \pm 2.38^{B,c}$	$37.25 \pm 2.44^{B,ab}$	$40.58 \pm 1.81^{B,a}$
	35°C	35.22 ± 0.45^{b}	20.63 ± 1.67^{c}	$23.12 \pm 2.25^{B,c}$	$21.10 \pm 4.24^{C,c}$	$34.65 \pm 1.43^{B,b}$	$36.56 \pm 3.06^{B,b}$	$44.29 \pm 2.40^{B,a}$
	45°C	35.11 ± 3.48^{b}	20.60 ± 3.87^{c}	$35.77 \pm 1.61^{A,b}$	$37.89 \pm 2.98^{A,b}$	$51.66 \pm 1.05^{A,a}$	$52.44 \pm 2.08^{A,a}$	$53.17 \pm 3.19^{A,a}$
Disulfide bonds (μmol/g protein)	5°C	41.88 ± 1.55^{c}	55.07 ± 2.60^{ab}	$56.10 \pm 1.35^{A,ab}$	$57.21 \pm 2.31^{A,a}$	$54.15 \pm 2.97^{A,ab}$	$52.34 \pm 1.81^{A,b}$	$52.67 \pm 1.73^{A,ab}$
	15°C	40.23 ± 1.49^{e}	55.47 ± 1.38^{ab}	$57.39 \pm 1.50^{A,a}$	$53.36 \pm 1.24^{A,b}$	$52.78 \pm 2.57^{A,b}$	$49.42 \pm 2.11^{A,c}$	$45.64 \pm 2.28^{B,d}$
	25°C	39.76 ± 0.57^{c}	56.14 ± 1.37^{a}	$56.33 \pm 1.37^{A,a}$	$53.05 \pm 2.08^{A,b}$	$51.70 \pm 2.37^{A,bc}$	$45.08 \pm 1.61^{A,d}$	$37.44 \pm 1.43^{C,d}$
	35°C	40.98 ± 0.45^{c}	57.81 ± 1.47^{a}	$55.84 \pm 0.62^{A,a}$	$46.77 \pm 2.07^{B,b}$	$40.24 \pm 2.08^{B,c}$	$33.48 \pm 2.61^{B,d}$	$28.76 \pm 2.37^{C,e}$
	45°C	41.34 ± 0.36^{c}	56.34 ± 0.71^{a}	$47.06 \pm 1.02^{B,b}$	$35.56 \pm 2.51^{C,d}$	$26.16 \pm 1.73^{C,e}$	$24.75 \pm 1.60^{C,ef}$	$22.64 \pm 2.28^{D,f}$

$^{A-C}$Means in the same column without a common superscript capital letter indicate a significant difference ($P < 0.05$).
$^{a-f}$Means in the same row without a common superscript lower case letter indicate a significant difference ($P < 0.05$). *Note:* Data are given as the mean ± SE ($n = 3$).

alkali-induced egg white gel. Such covalent bonds contribute one-third of the force maintaining a gel structure (Beveridge and Arntfield, 1979; Van der Plancken et al., 2005; Ji et al., 2013), and thus the thiol group and disulfide bond content can reveal the stability of an egg white gel. In the early stages of 150 mM-EWG gelation at reaction temperatures of 5, 15, 25, 35, or 45°C, the thiol group and disulfide bond contents were approximately 35 and 40 μmol/g, respectively. After 30 min, the thiol group content decreased to 20 μmol/g, and the disulfide bond content increased to 55 to 57 μmol/g (Table 2). This may be attributable to the fast exchange between thiol groups and disulfide bonds and the increase in disulfide bond content in the gel, which accelerates duck egg white gelation and enhances its structural stability (Mine, 1996). However, the disulfide bond content in the higher temperature groups began to drop after 1 h, with the drop continuing as time progressed. This may have occurred because the prolonged exposure to a strong alkali damaged the disulfide bonds, reducing them to thiol groups (Zhao et al., 2016a). The increase in thiol group content and decrease in disulfide bond content were particularly observable in 150 mM-EWG prepared at 45°C, which exhibited the phenomenon of liquefaction and a reduction in disulfide bond content to less than 26 μmol/g after 3 h. Conversely, keeping the alkali-induced egg white gel at 5°C for 0.5 to 5 h yielded a disulfide bond content of 52 to 57 μmol/g. Therefore, high temperature accelerated the strong alkali's damage to the gel, accelerated the exchange between thiol groups and disulfide bonds, reduced the disulfide bonds to thiol groups, and increased the possibility of gel liquefaction. These results were consistent with those of the bloom strength tests.

A SEM observation revealed the effect of temperature on the gel microstructures, as shown in Figure 3B. The 150 mM-EWG samples were prepared using reaction temperatures of 5, 15, 25, or 45°C and left to stand at their corresponding temperatures for 1 h. The gel prepared at 5°C had dense protein chains and aggregation, while the higher temperature resulted in a sparser microstructure with large holes. Zhao et al. (2016a) have suggested that alkali-induced egg white gel structures are formed through the aggregation of unfolded proteins and that the weakening of the mutual effects among protein chains could lead to larger gaps in the network structure and thus create more space for free water. Therefore, a high temperature may cause the forces between proteins in an alkali-induced gel to be seriously undermined by the strong alkali, weakening the gel structure and enlarging the holes in the microstructure. A relatively stable network structure, in which the bond forces in the gel (e.g., hydrogen, ion, or even disulfide bonds) are maintained, is produced under low temperature.

Alkali-induced egg white gels prepared through reactions between a sodium hydroxide solution and separated duck egg white at 5 or 15°C required an excessively long time to form, had inadequate bloom strength, and exhibited unfavorable viscous and elastic properties (Figures 1 and 2). Therefore, with the aim of reducing preparation time while maintaining favorable gel properties, that is, with the goal of facilitating the conversion of separated duck egg white into stable translucent egg white jelly products with gel properties, the separated duck egg white was alkali treated at 25°C to form alkali-induced egg white gels, namely translucent egg white jelly. The gels were then stored at 5°C to maintain the disulfide bonds in the gels and delay liquefaction.

Thermal Stability of Translucent Egg White Jelly

In general, preserved eggs are commonly directly heated to make dishes such as congee with pork and preserved egg or deep-fried preserved eggs. Accordingly, using separated duck egg white to produce translucent egg white jelly to be served hot can greatly diversify its application. The following subsections evaluate the thermal stability of the translucent egg white jelly.

Effect of Heating on the Bloom Strength and Appearance of Translucent Egg White Jelly The translucent egg white jelly stored at 5°C was heated in a water bath for 10 min at 60, 70, 80, 90, or 100°C to

Table 3. Effects of 10 min of heating at different water bath temperatures on the translucent egg white jelly's bloom strength, disulfide bond content, thiol group content, and release of free alkalinity.

Parameters	Groups	Heating temperature (°C)					
		Unheated	60	70	80	90	100
Bloom strength (g)	Control[1]	$80.12 \pm 2.71^{B,a}$	$56.08 \pm 1.90^{C,b}$	$42.56 \pm 1.30^{C,c}$	$24.06 \pm 1.07^{C,d}$	$15.72 \pm 0.93^{B,e}$	$11.01 \pm 0.99^{B,f}$
	Ginger	$79.18 \pm 2.35^{B,a}$	$66.38 \pm 1.24^{B,b}$	$52.12 \pm 1.33^{B,c}$	$46.39 \pm 0.78^{B,d}$	$40.76 \pm 2.30^{A,e}$	$34.38 \pm 1.48^{A,f}$
	Turmeric	$89.16 \pm 3.33^{A,a}$	$75.10 \pm 1.76^{A,b}$	$68.15 \pm 1.49^{A,c}$	$52.11 \pm 1.26^{A,d}$	$43.97 \pm 2.37^{A,e}$	$40.04 \pm 0.62^{A,e}$
Disulfide bonds (μmol/g protein)	Control	$53.13 \pm 2.41^{B,a}$	$50.01 \pm 1.11^{A,a}$	$44.12 \pm 1.52^{A,b}$	$42.40 \pm 0.70^{A,b}$	37.50 ± 0.53^{c}	$38.73 \pm 0.99^{A,c}$
	Ginger	$53.76 \pm 2.12^{B,a}$	$37.45 \pm 0.41^{C,b}$	$34.51 \pm 0.56^{B,b,c}$	$31.57 \pm 1.23^{C,c}$	$33.66 \pm 0.54^{b,c}$	$32.22 \pm 1.80^{B,b,c}$
	Turmeric	$63.27 \pm 0.59^{A,a}$	$41.69 \pm 0.60^{B,b}$	$40.98 \pm 2.39^{A,b}$	$37.30 \pm 1.32^{B,b,c}$	36.13 ± 1.44^{c}	$35.15 \pm 0.42^{B,c}$
Free alkalinity content (mg/100 g)	Control	14.85 ± 0.11^{c}	15.97 ± 0.16^{c}	18.26 ± 0.13^{b}	17.78 ± 0.44^{b}	$23.11 \pm 0.59^{A,a}$	$25.33 \pm 0.77^{A,a}$
	Ginger	14.24 ± 0.16^{bc}	13.83 ± 0.45^{c}	$17.44 \pm 0.22^{a,b}$	15.78 ± 0.22^{b}	$16.22 \pm 0.22^{C,b}$	$18.44 \pm 0.59^{B,a}$
	Turmeric	15.08 ± 0.07^{b}	13.95 ± 1.18^{c}	$17.89 \pm 0.40^{a,b}$	$17.56 \pm 0.80^{a,b}$	$19.33 \pm 0.38^{B,a}$	$20.89 \pm 1.46^{B,a}$

[1]Control refers to translucent egg white jelly prepared using an alkali-treated egg white solution containing 150 mM sodium hydroxide produced by mixing 80% separated duck egg white with 20% sodium hydroxide and maintaining a 25°C reaction temperature. Ginger and Turmeric refer to translucent egg white jellies prepared with the same procedure but with the addition of 0.5% ginger juice powder and 0.5% turmeric powder, respectively.

[A–C]Means in the same column without a common superscript capital letter indicate a significant difference ($P < 0.05$).

[a–f]Means in the same row without a common superscript lower-case letter indicate a significant difference ($P < 0.05$). *Note:* All samples were stored at 5°C for 24 h before measuring. Data are given as the mean ± SE ($n = 3$).

determine the effect of heating on bloom strength (Table 3). The translucent egg white jelly had bloom strength of 80 g before heating, but had significantly reduced bloom strengths at higher temperatures ($P < 0.05$). When the temperature reached 100°C, the bloom strength decreased to approximately 11 g. Moreover, the disulfide bond content in the translucent egg white jelly heated to 60°C did not differ significantly from that in the unheated sample ($P > 0.05$). This signifies that heating at a low temperature had a limited effect on the number of covalent bonds in the alkali-induced egg white gels. However, when the jelly was heated to over 70°C, the total disulfide bond content decreased significantly as the temperature rose ($P < 0.05$); this result was consistent with that of the bloom strength test, in that heat damaged the disulfide bonds between protein molecules and thus reduced the bloom strength of the egg white jelly. Badii and Howell (2006) reported that heating leads to the exposure of proteins' hydrophobic groups, thereby increasing the hydrophobic interaction and gel strength. This is the opposite of our findings in this study; we therefore inferred that globular protein structures such as ovalbumin had unfolded in the early stages of the reaction between the duck egg white and strong alkali. As the exposure to the strong alkali proceeded, the unfolded ovalbumin formed a well-arranged network gel structure due to crosslinking between the disulfide, ion, and hydrogen bonds (Clark, 1992). Once an alkali-induced egg white gel has formed, heating can damage the bonds that uphold the gel structure, with the magnitude of damage increasing with temperature. Although heating caused the bloom strength to drop and texture to soften, the translucent egg white jelly retained its solid appearance after heating and did not exhibit signs of liquefaction or structural collapse (Figure 4A), rendering the jelly a potential heatable food ingredient.

Effect of Heating on the Microstructure of Translucent Egg White Jelly Scanning electron microscopy was employed to observe the effect of heating on the microstructure of the translucent egg white jelly, which revealed significant changes (Figure 4B). After the jelly was heated in a water bath for 10 min, the microstructure was densified and the holes in the network structure shrank. By contrast, the unheated jelly had a sparser microscopic structure with larger holes. Additionally, as the temperature increased, the protein chains grew thicker, and the degree of crosslinking increased, which reduced hole size. This may have occurred because heating enhanced protein aggregation and led to the contraction or even dehydration of the gel network structure, further increasing the density of the structure. Woodward and Cotterill (1986) heated hen egg white at 80°C for 10, 12, and 15 min and used SEM to examine the microscopic structure of the resultant egg white gels. The microstructure of the heat-induced hen egg white gel became denser and had a reduced area and number of holes as heating time increased; after heating for 15 min, most holes in the gel structure were filled with network branches, particles were observed on the surface, and the gel comprised a continuous network structure. Many studies have argued that the main difference between heat-induced and alkali-induced egg white gels is that alkali results in an unfolding and linear arrangement of proteins, thereby yielding a well-arranged network structure, whereas heating causes denatured protein particles to aggregate and form a dense structure (Kitabatake et al., 1987; Tani et al., 1993; Chen et al., 2015). In this study, when the translucent egg white jelly was heated, its microstructure closely resembled that of a heat-induced egg white gel.

Effect of Heating on the Color Properties of Translucent Egg White Jelly As seen in Figure 4A, concurrent exposure to a strong alkali and high temperature resulted in the level of brownness in the translucent egg white jelly increasing with the temperature. When the temperature reached 90°C or higher, the gel exhibited a brown color similar to that of preserved egg white. The

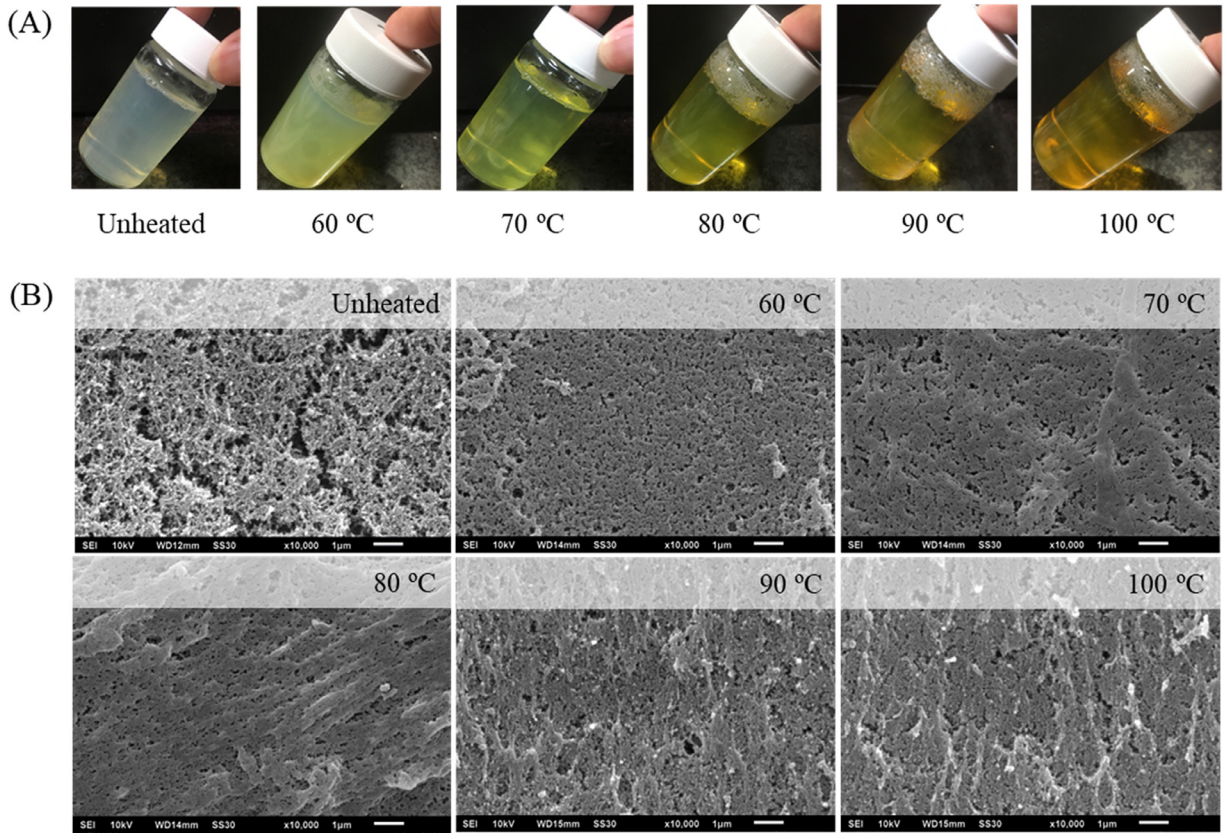

Figure 4. (A) Appearances and (B) scanning electron microscopy images of the microstructures of translucent egg white jellies after heating for 10 min at different temperatures. Magnification: 10,000 ×.

color properties revealed that the lightness (L*) and whiteness of the translucent egg white jelly significantly decreased as the temperature increased ($P < 0.05$), while the redness (a*) and yellowness (b*) significantly increased with temperature ($P < 0.05$; Table 4). Zhao et al. (2014b) reported that alkali-induced egg white gels exhibit an amber color like that of preserved egg white. The unique dark-brown color of preserved egg white has been attributed to the fact that high-pH environments promote the Maillard reaction between free amino groups and glucose (Ganasen and Benjakul, 2011, 2014). Benjakul et al. (2005) suggested that preserved egg white generates various intermediate products, including fluorescent and non-fluorescent compounds, during the Maillard reaction and that the fluorescent compounds may be the precursors of brown pigments (Baiser and Labuza, 1992; Morales et al., 1996). In the present study, the egg white jelly maintained its appearance as a translucent gel, but it increased in darkness after heating, which is consistent with previous findings that alkali-induced protein gels and preserved egg white retain their translucent appearance after heating (Kitabatake et al., 1987; Liu and Yang, 1992). Li et al. (2018) found that if the pH of a duck egg white solution was increased before heating by adding 0.4% sodium hydroxide, the solution did not form an alkali-induced gel due to the alkaline deficiency. However, the heating also did not cause the thermal denaturation and coagulation of proteins in the alkali-treated egg white protein due to the removal of the heat-denaturing properties at 50 to 70°C. This was likely because the strong alkali induced the proteins to structurally unfold or degrade, making it impossible for the protein particles to aggregate and hence form heat-

Table 4. Color properties of translucent egg white jelly after heating treatments.

	Color properties			
Heating temperature (°C)	L*	a*	b*	Whiteness[1]
Unheated	80.91 ± 2.56^{a}	-4.53 ± 0.55^{b}	21.16 ± 1.20^{e}	70.96 ± 1.67^{a}
60	78.17 ± 1.39^{ab}	-9.33 ± 0.33^{e}	19.18 ± 2.70^{e}	69.37 ± 2.40^{a}
70	77.41 ± 1.80^{ab}	-9.04 ± 0.49^{de}	28.87 ± 0.98^{d}	62.14 ± 0.80^{b}
80	73.54 ± 2.11^{bc}	-7.30 ± 0.10^{cd}	36.46 ± 3.38^{c}	54.13 ± 2.25^{c}
90	69.90 ± 0.15^{c}	-6.79 ± 0.99^{c}	53.75 ± 1.17^{b}	38.00 ± 0.93^{d}
100	61.43 ± 1.82^{d}	3.57 ± 0.63^{a}	69.52 ± 3.33^{a}	20.28 ± 2.03^{e}

Note: Data are given as the mean ± SE ($n = 3$).
L*, lightness; a*, redness; b*, yellowness.

[1]Whiteness $= 100 - \sqrt{(100 - L^{*})^{2} + a^{*2} + b^{*2}}$

[a–e]Means in the same column without a common superscript letter indicate a significant difference ($P < 0.05$).

induced egg white gels, even when subjected to heating. We inferred that heating does not prevent stable translucent egg white jelly from maintaining a translucent gel appearance similar to that of preserved egg white or turn it into an opaque heat-coagulated white gel.

Effect of Ginger and Turmeric on the Physiochemical Properties and an Organoleptic Evaluation of Translucent Egg White Jelly After Heating

Given the common adoption of ginger and turmeric as flavorings to hide odors in dishes such as ginger duck hot pot or turmeric-curry-flavored meat, we mixed ginger or turmeric with the separated duck egg white to produce flavored translucent egg white jellies and evaluated their performance in improving the jelly's texture, thermal stability, and organoleptic properties.

Effect on the Physiochemical Properties of Translucent Egg White Jelly First, ginger powder and turmeric powder were separately dissolved in a sodium hydroxide solution and mixed evenly with separated duck egg white to produce a flavored egg white jelly with 0.5% ginger or 0.5% turmeric. The physiochemical properties of the jellies were then compared with those of the control sample, unflavored egg white jelly; Table 3 presents the results. Before heating, the bloom strength of the translucent egg white jelly flavored with turmeric was significantly higher than those of the others ($P < 0.05$). After the three were heated in a water bath for 10 min at the same temperature, the 2 flavored jelly samples had significantly higher bloom strengths than the control sample ($P < 0.05$), with the turmericturmeric-flavored jelly having a slightly higher bloom strength than the ginger-flavored jelly. Notably, even when heated to 100°C, the bloom strengths of the 2 flavored jellies were still higher than 30 g. Therefore, ginger and turmeric were both conducive to maintaining gel structure and preventing liquefaction. However, the bloom strengths of the egg white gels decreased as the temperature increased. This phenomenon was assumed to be associated with damage to the disulfide bonds maintaining the egg white gels' structures. However, the egg white jellies containing ginger or turmeric also exhibited a significantly decreased disulfide bond content with increasing temperature ($P < 0.05$), and the decrease was even more prominent than in the control sample. Notably, after heating at 60 to 100°C for 10 min, the ginger- and turmeric-flavored egg white jellies had bloom strengths higher than that of the control sample and the appearance of an intact gel. Therefore, adding ginger or turmeric enhanced bloom strength without increasing the number of disulfide bonds. Liu et al. (2017) reported that the integration between ovalbumin and curcumin changed the crystal structure of curcumin, the secondary structure of ovalbumin, and the hydrophobicity at the protein surface, changes that were conducive to the formation of gel network structures. Regarding the effect of ginger, Latona et al. (2012) and Felfoul et al. (2017) have reported that adding ginger juice to cow milk helps to increase the surface viscosity and hardness as well as decrease syneresis in fermented milk, because the solids in ginger juice have a high protein content and are over 40% starch. According to Sarkar and Alam (2018), ginger contains protease and thus can be used to produce ginger-flavored curd by mixing it with milk at 60°C. Therefore, the addition of ginger or turmeric may enhance the bloom strength of a protein jelly by changing the hydrophobic force between the protein bonds or by increasing the solid content. All 3 egg white jellies had a disulfide bond contents higher than 30 μmol/g after being heated at 100°C for 10 min. However, liquefaction occurred when the content was less than 27 μmol/g (Table 2). Thus, keeping an egg white jelly at 5°C before heating it can help the jelly maintain a certain level of stability and hence prevent unfavorable phenomena such as liquefaction from occurring.

Effect on the Free Alkalinity of Translucent Egg White Jelly The egg white gels of preserved eggs remain stable after being cooked with hot congee or lean meat, and even after being deep-fried. Accordingly, we investigated the free alkali content released from the translucent egg white jelly into hot water during heating to look for insightful indicators of gel structure stability. Supplementary Figure 1 contains the results of heating preserved egg white gels available on the market, showing that they released a significantly larger amount of alkaline substances than did the egg white jelly in our study ($P < 0.05$). In particular, when heated to 100°C for 10 min, the free alkali released from the preserved egg white gels and the egg white jelly increased to 45 mg/100 g and 25 mg/100 g, respectively. Generally, hydroxide ions in alkali-induced egg white gels combine with water molecules to form stable hydrogen bonds. Heating causes the hydroxide ions originally in the gels to be released into the environment, with higher temperatures leading to greater release. According to Table 3, the amount of free alkali released from the egg white jelly increased with temperature ($P < 0.05$). However, compared with the control samples heated at corresponding temperatures, the egg white jelly with ginger juice or turmeric released less free alkali after being heated at 60, 70, or 80°C for 10 min; the amount of free alkali was also significantly less than that of the control samples when heated to 90 or 100°C ($P < 0.05$). The results also revealed that the higher the bloom strength of the egg white jelly, the less liberation of free alkali, which confirmed that a more intact gel structure was associated with lower amounts of alkaline substances being released. Adding ginger juice or turmeric hid the odor of the duck egg white, significantly enhanced the bloom strength, and effectively delayed egg white liquefaction, showing that their addition increased the egg white jellies' stabilities. Accordingly, and similar to the preserved eggs on the market now that are served in hot congee, the translucent egg white jelly with ginger juice

Table 5. Organoleptic evaluation of unheated and heated translucent egg white jelly.

Samples	Appearance	Aroma	Texture	Flavor	Total acceptability
Unheated					
Control[1]	5.47 ± 0.25	4.57 ± 0.20	5.83 ± 0.22	4.43 ± 0.31	4.77 ± 0.27
Ginger	5.67 ± 0.26	5.17 ± 0.26	5.53 ± 0.22	4.50 ± 0.44	4.83 ± 0.26
Turmeric	4.90 ± 0.84	5.07 ± 0.95	5.83 ± 0.73	4.27 ± 1.07	4.63 ± 1.06
Heated					
Control	5.77 ± 0.29	4.73 ± 0.30[b]	5.57 ± 0.25	4.70 ± 0.31	5.13 ± 0.25
Ginger	5.80 ± 0.24	5.27 ± 0.25[ab]	5.77 ± 0.28	5.10 ± 0.33	5.53 ± 0.23
Turmeric	5.53 ± 0.99	6.03 ± 0.84[a]	5.70 ± 0.86	5.07 ± 0.79	5.53 ± 0.75

[1]Control refers to translucent egg white jelly prepared using an alkali-treated egg white solution containing 150 mM sodium hydroxide produced by mixing 80% separated duck egg white with 20% sodium hydroxide and maintaining a 25°C reaction temperature. Ginger and Turmeric refer to translucent egg white jellies prepared with the same procedure but with the addition of 0.5% ginger juice powder and 0.5% turmeric powder, respectively.

[a,b]Means in the same column without a common superscript letter indicate a significant difference ($P < 0.05$). *Note:* Data are given as the mean ± SE ($n = 50$).

or turmeric an appropriate ingredient for cooking and for instant foods.

Effect on Organoleptic Properties of Translucent Egg White Jelly Ginger and turmeric enhanced the thermal stability and bloom strength of egg white jelly while also mitigating the odor. Therefore, we conducted a hedonic evaluation to determine the acceptability of egg white jelly in relation to various indicators. Table 5 presents the results of the organoleptic evaluation for unheated and heated unflavored egg white jelly, egg white jelly with ginger, and egg white jelly with turmeric. For the unheated egg white jelly, no significant between-group difference ($P > 0.05$) was present for appearance, aroma, texture, flavor, or total acceptability. After being heated at 80°C for 10 min, the egg white jelly maintained its translucent appearance (Figure 4A), and the jellies with ginger or turmeric outperformed the control sample with respect to aroma, texture, flavor, and total acceptability. The jelly with turmeric had a significantly higher aroma rating (by 6 points) than the control sample ($P < 0.05$); this may be because turmeric has the strongest aroma, followed by ginger, and both successfully masked the odor of the duck egg white and thus boosted its acceptance among the panelists. However, the red translucent appearance of the egg white jelly with turmeric was less accepted by the panelists, resulting in a lower rating on the appearance dimension. Overall, the proposed translucent egg white jellies with ginger or turmeric had higher stability and acceptance ratings in comparison with the control sample, and after heating, they maintained their gel properties and scored higher than 5 on all organoleptic indicators. Accordingly, the proposed translucent and springy duck egg white jelly is suitable as a food ingredient in salads and can be served hot or in a hot pot, thus putting excess duck egg whites to diverse use.

CONCLUSIONS

Using separated duck egg white to produce translucent egg white jelly through an alkaline treatment mitigated the difficulties in storing and transporting excess duck egg white, increased its usefulness, and added value. Its strong odor was also covered. The proposed translucent egg white jelly is similar to preserved egg white in terms of its translucency and springiness, and it is a suitable ingredient for salads. Despite softening and having reduced bloom strength after heating, the jelly maintained its gel integrity, did not liquefy, and compared with preserved eggs on the market, released a lower level of free alkali during heating. Adding ginger or turmeric during the preparation inhibited its odor, improved its flavor and acceptance, and enhanced its bloom strength and stability during heating. Accordingly, this study successfully developed a heatable translucent egg white jelly that was similar to preserved egg white. Due to its richness in proteins and potential to be served either hot or instantly without heating, this egg white jelly can mitigate the excessive remaining duck egg white created during food processing, diversify duck egg processing applications, and boost the added value of duck eggs.

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DISCLOSURES

The authors declare that there are no conflicts of interest.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.psj.2021.101373.

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