PROCESSING, PRODUCTS, AND FOOD SAFETY

Effects of alkaline concentration, temperature, and additives on the strength of alkaline-induced egg white gel

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ABSTRACT Egg whites can undergo gelation at extreme pH. In this paper, the effects of NaOH concentration (1.5, 2, 2.5, and 3%), temperature (10, 20, 30, and 40°C), and additives (metallic compounds, carbohydrates, stabilizers, and coagulants) on the strength of alkaline-induced egg white gel were investigated. Results showed that NaOH concentration and induced temperature significantly affected the rate of formation and peak strength of the egg white gel. Of the 6 metallic compounds used in this experiment, $CuSO_4$ exhibited the optimal effect on the strength of alkaline-induced egg white gel, followed by $MgCl_2$, $ZnSO_4$, PbO, and $CaCl_2$. When $CuSO_4$ concentration was 0.2%, the gel strength increased by 31.92%. The effect of $Fe_2(SO_4)_3$ was negligible. Of the 5 carbohydrate additives, xanthan gum (0.2%) caused the highest increase (54.31%) in the strength of alkaline-induced egg white gel, followed by sodium alginate, glucose, starch, and sucrose. Meanwhile, propylene glycol (0.25%) caused the highest improvement (15.78%) in the strength of alkaline-induced egg white gel among the 3 stabilizing agents and coagulants used, followed by Na_2HPO_4 and glucono-δ-lactone.

Key words: egg white, gel strength, alkaline, additive

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INTRODUCTION

Egg white is rich in various types of proteins, including ovalbumin, conalbumin, ovomucoid, lysozyme, and so on (Mine, 2008). Several these proteins become denatured and form gels under heating, at extreme pH, or in the presence of metal ions (Mine, 1996; Croguennec et al., 2002; Campbell et al., 2003; Handa et al., 2008). Thus, egg white is widely used in surimi, meat, and noodle products because of its gelation property (Dawson et al., 1990; Liu et al., 2011; Park, 2006; Reppond et al., 2006).

Preserved egg, also known as pidan (in Chinese), hundred-year egg, thousand-year egg, century egg, and millennium egg, is a traditional Chinese egg delicacy. It is prepared by pickling fresh duck eggs, chicken eggs, or quail eggs in a mixture of alkali, salt, black tea, and metal ions at room temperature for 4 to 5 wk (Su and Lin, 1993; Wang and Fung, 1996). Without heating, both the egg white and egg yolk can form gels after fresh eggs are processed into preserved eggs. The gel properties, particularly those of the egg white gel, directly affect the quality of the preserved egg. The typical characteristic of a preserved egg is determined by the properties of its egg white gel (Tu et al., 2012). However, in the commercial process of preserved eggs, egg white gels cannot be formed well without the regulation of metal ions, such as lead and copper (Ganasen and Benjakul, 2010; Ganesan and Benjakul, 2010; Tu et al., 2013a). Given that preserved eggs are mainly soaked in strong alkaline solutions, the appropriate amount of metal ions must be added into the pickling liquid to prevent excess alkali from damaging the preserved egg white gel during postpickling (Zhao et al., 2010). During pickling, metal ions form insoluble sulfur compounds that can plug the shell and membrane pores and mesh the corrosion holes generated during alkali processing (Zhao et al., 2010). Therefore, the addition of metal ions prevents the excessive infiltration of alkali. However, excessive mineral intake is harmful to human health. For example, Pb accumulation causes damage to the human nervous, digestive, and circulatory systems. Excess Cu intake causes stomach upset, nausea, and diarrhea and can also lead to

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chronic copper toxicity, including cirrhosis of the liver, Indian childhood cirrhosis, and Tyrolean infantile cirrhosis (Baos et al., 2006; Uauy et al., 2008). Therefore, alternative pickling processes that do not require the addition of metal ions must be developed. However, the gel-forming mechanisms of egg white during preserved egg preparation are unclear. Moreover, studies on the factors affecting egg white gel properties induced by NaOH are currently insufficient. As a result, the development of alternative technologies for preserving eggs lacks theoretical guidance.

The pickling of preserved eggs is time consuming. Therefore, this paper aims to investigate the factors affecting the strength of strong alkali-induced duck egg white gel outside the egg and to provide data for developing alternative pickling technologies for preserved eggs without the addition of metals.

MATERIALS AND METHODS

Materials

Fresh duck eggs were obtained within 1 d of laying from a farm in Nanchang County, Jiangxi Province, China. Analytically pure sodium hydroxide (NaOH), copper sulfate ($CuSO_4$), zinc sulfate ($ZnSO_4$), ferric sulfate [$Fe_2(SO_4)_3$], magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), lead oxide (PbO), sodium phosphate dibasic (Na_2HPO_4), glucose, sucrose, sodium alginate, and propylene glycol were purchased from Sinopharm Chemical Reagent Co. Ltd. (Shanghai, China). Food-grade xanthan gum and glucono-δ-lactone (**GDL**) were obtained from Shanghai Lvzhou Food Additive Co. Ltd. (Shanghai, China). Starch was purchased from Hebei Huachen Starch Sugar Co. Ltd. (Hebei, China).

Preparation of Egg White Gels

The egg white and egg yolk of fresh duck egg were manually separated with an egg yolk separator. The egg white was then uniformly stirred in a blender. The prepared fresh duck egg white was poured into plastic beakers. Sodium hydroxide and additive solutions were added to the egg white, and the mixture was immediately stirred with a glass rod. The beakers were covered with a tinfoil and then placed into constant-temperature baths (Brookfield, Middleboro, MA). The gel plugs that formed in the beakers were collected, and the gel strength was determined using a CT3–100 texture analyzer (Brookfield).

Determination of Gel Strength

The gel strength of the samples formed under various treatments was determined using a single-compression cycle model with a CT3–100 texture analyzer. The gel strength was represented by the measured hardness (g). The measurement parameters were as follows: pretest speed of 2 mm/s, test speed of 0.5 mm/s, posttest speed of 0.5 mm/s, target distance of 6 mm, and trigger point load of 3 g. The probe used was a TA10 cylindrical probe (12.7 mm). Data acquisition and analysis were completed using texture loader software (Brookfield).

Effect of NaOH Concentration on the Gel Strength of Duck Egg White

First, 15, 20, 25, and 30 g of sodium hydroxide was put into a plastic beaker, respectively. Then 1,000 mL of distilled water was added into each beaker to prepare 1.5, 2, 2.5, and 3% of sodium hydroxide solution. After this cooled down, 10 mL of NaOH prepared was added into a plastic beaker with 20 mL of fresh duck egg white, respectively. They were mixed by a glass rod at a fast speed, then sealed with plastic wrap, and were placed in a water bath with a temperature of 20°C. After the gel was formed, strength of samples was measured at various time intervals.

Effect of Induced Temperature on the Gel Strength of Duck Egg White

Ten milliliters of sodium hydroxide solution (1.5%) was prepared and added into a plastic beaker with 20 mL of fresh duck egg white. After mixing, they were placed in a water bath with a temperature of 10, 20, 30, and 40°C, respectively. After the gel was formed, strength of samples was determined at set intervals.

Effects of Different Additives on the Strength of NaOH-Induced Egg White Gel

First, 0.8 g of copper sulfate, calcium chloride, magnesium chloride, lead oxide, zinc sulfate, ferric sulfate, glucose, sucrose, xanthan gum, or starch, 4 g of each gluconolactone, sodium phosphate dibasic, or propylene glycol was added, respectively, into beakers. Then 100 mL of distilled water was added into each beaker to prepare 0.8% of metal salt solution. After this, 50 mL of solution was added into another beaker, and then 50 mL of distilled water was added to become the concentration of 0.4% solution (metallic compounds and carbohydrates: copper sulfate, calcium chloride, magnesium chloride, lead oxide, zinc sulfate, ferric sulfate, glucose, sucrose, xanthan gum, and starch) and 2% solution (stabilizer and coagulants: gluconolactone, sodium phosphate dibasic, and propylene glycol). Diluting continued until a concentration of 0.05% solution (metallic compounds and carbohydrates) and 0.25% stabilizer and coagulants. Five milliliters of the above prepared additive solution was added in the beaker containing 20 mL of egg white, and 5 mL of sodium hydroxide solution (5%) was added and then mixed uniformly. After 105 min at 20°C, the strength of samples was determined.

Statistical Analysis

All experiments were replicated 6 times. The results were expressed as means ± SD. Statistical analysis was performed using the Student's *t*-test by SPSS 11.5 (SPSS Inc., Chicago, IL). Differences were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Effect of NaOH Concentration on the Gel Strength of Duck Egg White

Preserved eggs are traditionally made by pickling fresh duck eggs in a mixture of calcined lime, sodium carbonate, salt, and black tea (Ma, 2007). Given that this method results in considerable precipitation at the bottom of the container, NaOH is used mainly to replace calcined lime and sodium carbonate in modern industrial processes. Therefore, NaOH was chosen to be used in this study.

The duck egg white gel was relatively soft during the preliminary experiments when the NaOH concentration exceeded 3% at 20°C, the gel strength rapidly decreased, which resulted in low stability and large measurement errors. Therefore, the NaOH concentrations used in this experiment were 1.5, 2.0, 2.5, and 3%.

The effect of NaOH concentration on the gel strength of duck egg white is shown in Figure 1. The strength of the 1.5% NaOH-induced egg white gel gradually changed over time; the value initially increased to a maximum of 34.20 ± 1.34 g at 9 h and then gradually decreased to 27.71 ± 0.85 g at 15 h (Figure 1a). The change in the strength of the 2% NaOH-induced egg white gel was about twice as fast as that of the 1.5% NaOH-induced gel. The value reached the maximum of 33.91 ± 1.47 g at 5 h and then gradually decreased to 26.47 ± 0.99 g at 13 h. Meanwhile, the strength of the 2.5% NaOH-induced gel rapidly changed over time. The value reached the maximum of 32.38 ± 1.66 g at 1.75 h and then gradually decreased to 28.64 ± 1.32 g at 5 h. The strength of the 3% NaOH-induced egg white gel rapidly changed over time. The value reached the maximum of 28.71 ± 1.11 g at 1 h and then rapidly decreased to 22.25 ± 0.31 g at 3 h.

The above results showed that the strength of strong alkaline-induced duck egg white gel initially increased and then decreased with time. High NaOH concentrations rapidly increased the strength of the duck egg white gel to the maximum value and then caused the value to rapidly decrease. By contrast, the strength of low-concentration NaOH-induced egg white gel was highly stable and exhibited gradual changes over time. As a strong alkali, NaOH can induce the denaturation

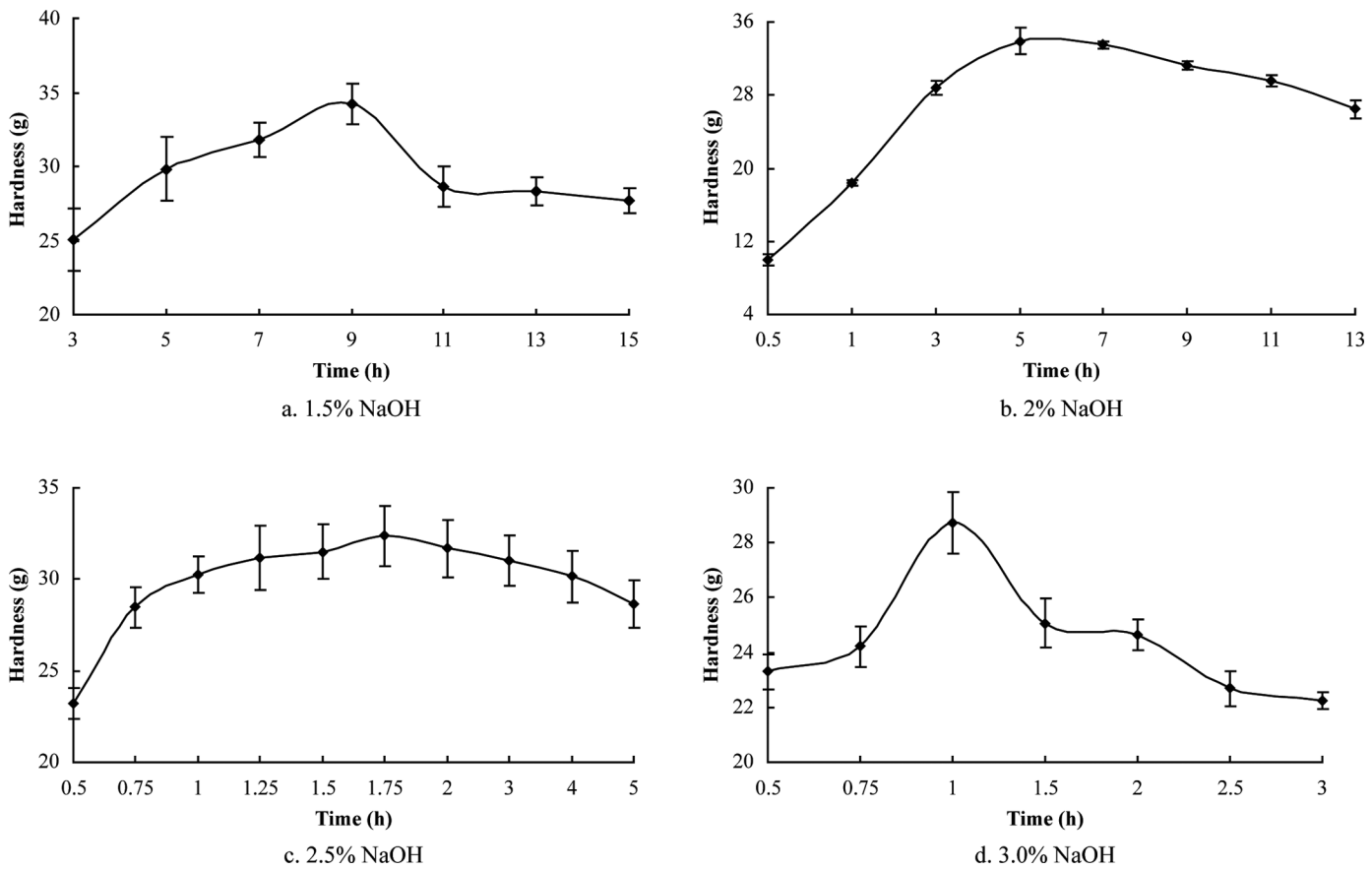

Figure 1. Effect of NaOH concentration on the gel strength of duck egg white (20°C): (a) 1.5%, (b) 2.0%, (c) 2.5%, and (d) 3.0% NaOH. The data were expressed as means ± SD.

of proteins when added to fresh egg white. In the presence of NaOH, the secondary structure of the denatured proteins was destroyed, hydrogen bonds were broken, and the number of hydrophilic groups increased. These phenomena enhanced the hydrophilic property of protein molecules; interaction between these protein molecules resulted in the formation of a new aggregate (Ji et al., 2013). The liquefaction occurred when the amount of alkali in the egg white exceeded the optimal value or treatment time exceeded the optimal time. Therefore, during preserved egg preparation, the excessively high NaOH concentration in the pickling solution or the long incubation time may have caused the degradation of the egg white gel, and the aggregated gel readily turned into liquid. This phenomenon is called alkali injury. However, low NaOH concentrations are not conducive to egg white aggregation and result in softer products and longer maturation time. Therefore, during the preparation of preserved eggs, the NaOH concentration should be controlled to obtain the desired texture.

Effect of Temperature on the Gel Strength of Duck Egg White

When the NaOH concentration was 1.5%, the gel strength peak was 34.20 ± 1.34 g, and the gel was significantly more stable at 20°C. Thus, the 1.5% NaOH concentration was used in the group experiments. The effects of different temperatures (10, 20, 30, and 40°C) on the strength of the 1.5% NaOH-induced egg white gel are shown in Figure 2. At 10°C, the change in the gel strength was slower as the induction time increased. The strength reached the maximum of 34.73 ± 0.43 g at 11 h and then gradually decreased to 21.77 ± 0.65 g at 23 h. At 20°C, the change in the gel strength was slightly faster, as shown in Figure 2b. Meanwhile, the gel strength rapidly changed at 30°C. It reached the maximum of 29.50 ± 1.43 g at 2.5 h and then gradually decreased to 26.34 ± 1.25 g at 4 h. The change in the gel strength was significantly rapid at 40°C. The strength reached the maximum of 31.76 ± 1.59 g at 1.5 h and subsequently decreased rapidly to 28.32 ± 0.79 g at 3 h.

These results showed that the strength of the egg white gels initially increased to a peak and then decreased over time, indicating that temperature significantly affects the rate of NaOH permeation into the egg white. The permeation rate is high at high temperatures, whereas the rate is low at low temperatures. In a similar manner, temperature is one of the most important pickling factors that determine the solidification of preserved egg white and yolk. Temperature also affects the egg color. A high pickling temperature and a considerably long curing time disrupt the egg white gel structure and cause the liquefaction of the aggregated gels, resulting in low product quality (Zhang, 2004; Yang et al., 2012). If the pickling temperature

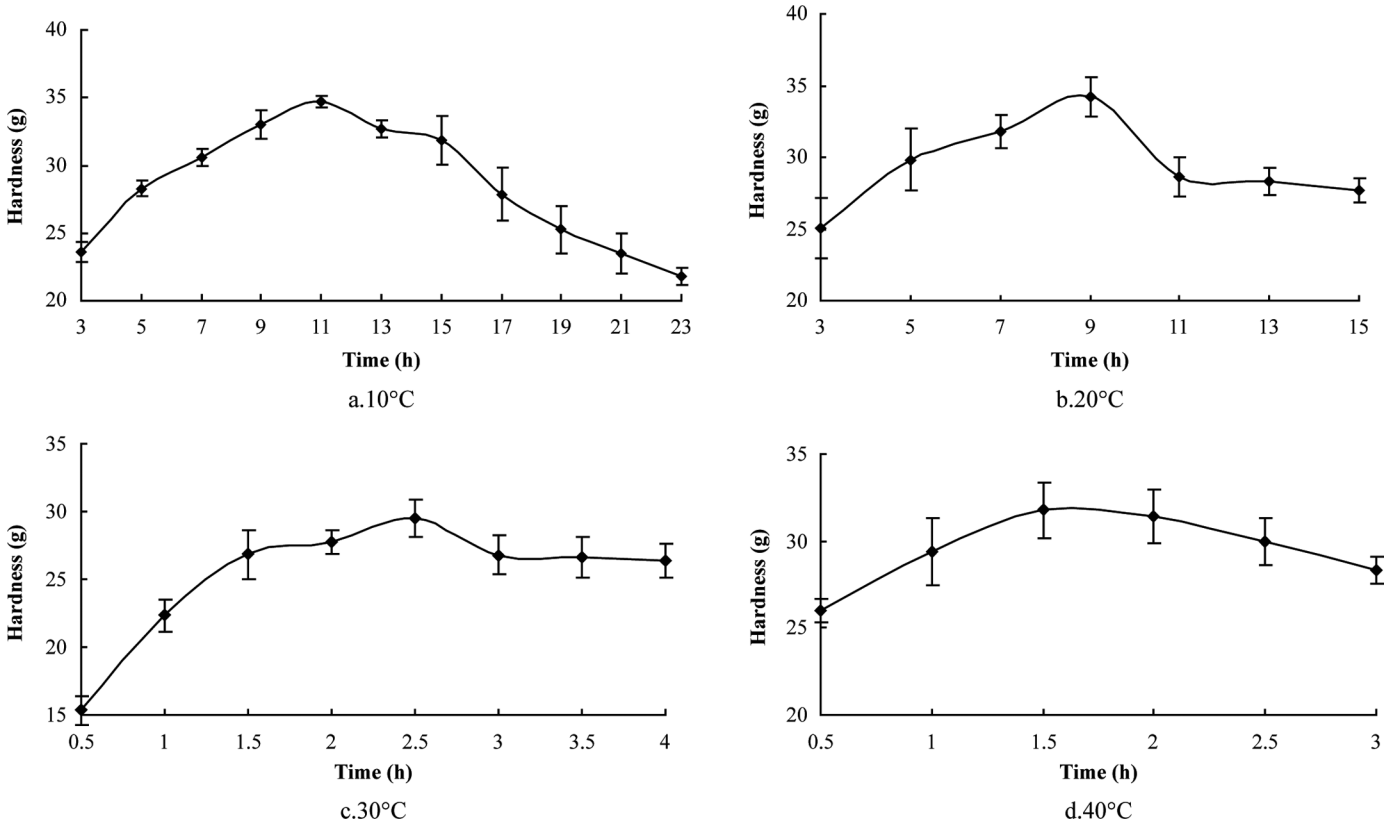

Figure 2. Effect of temperature on the gel strength of duck egg white (NaOH 1.5%): (a) 10°C, (b) 20°C, (c) 30°C, and (d) 40°C. The data were expressed as means ± SD.

is extremely low, the processing cycle of the preserved egg is lengthened; a long processing time has adverse effects on yolk coloring and results in the formation of defective yellow eggs (Lu et al., 2005). The choice of the pickling temperature is highly critical in obtaining preserved egg products with favorable textures and colors.

Effects of Different Additives on the Strength of NaOH-Induced Egg White Gel

The peak strength of egg white gel was obtained under 2.5% NaOH and at a processing time of 105 min. This processing time is shorter than that of 1.5 and 2.0% NaOH, and the gel quality obtained was better than that from 3% NaOH. Therefore, to save time, 2.5% NaOH was used in the group experiments. The gel strength of egg white can be affected by the quality of the raw eggs, as well as by several external factors and instrumental errors during the course of the experiment. Therefore, different blanks were prepared for different groups of additives.

Effects of Different Metallic Compounds on the Strength of NaOH-Induced Egg White Gel

Figure 3 shows the gel strength of egg white induced by 2.5% NaOH for 105 min at 20 °C and with or without 0.025, 0.05, 0.1, 0.2, or 0.4% metallic compounds [$CuSO_4$, $CaCl_2$, $MgCl_2$, PbO, $ZnSO_4$, and $Fe_2(SO_4)_3$]. The addition of 0.025 or 0.05% $CaCl_2$ reduced the gel strength of the egg white. However, 0.1, 0.2, or 0.4% of $CaCl_2$ increased the gel strength. The 0.1% $CaCl_2$ concentration exhibited the optimal effect on increasing gel strength by 7.19% compared with that of the control. Meanwhile, at $CuSO_4$ concentrations below 0.2%, the gel strength of the egg white gradually increased as the $CuSO_4$ concentration increased. When the $CuSO_4$ concentration was 0.2%, the gel strength increased by 31.92%. However, when the $CuSO_4$ concentration was 0.4%, the gel strength decreased by 4.40% of the 0% $CuSO_4$. The addition of <0.4% $ZnSO_4$ increased the gel strength of the egg white. For $ZnSO_4$, 0.05% was the optimal concentration, which increased the gel strength by 17.23% compared with that of the control. When the $MgCl_2$ concentration was below 0.4%, the gel strength gradually increased with increasing $MgCl_2$ concentration. When 0.4% $MgCl_2$ was added, the gel strength increased by 24.06% from the control value. By contrast, the addition of 0.025 and 0.05% PbO reduced the gel strength. The addition of 0.1, 0.2, and 0.4% PbO improved the gel strength. For PbO, 0.4% was the optimal concentration, as indicated by the 7.35% increase in the gel strength compared with the control. The results also showed that the gel strength decreased when the $Fe_2(SO_4)_3$ concentration was below 0.4%. When the $Fe_2(SO_4)_3$ concentration was below 0.2%, the gel strength gradually decreased with increasing concentration. However, when the $Fe_2(SO_4)_3$ concentration was 0.4%, the strength was slightly higher than the control.

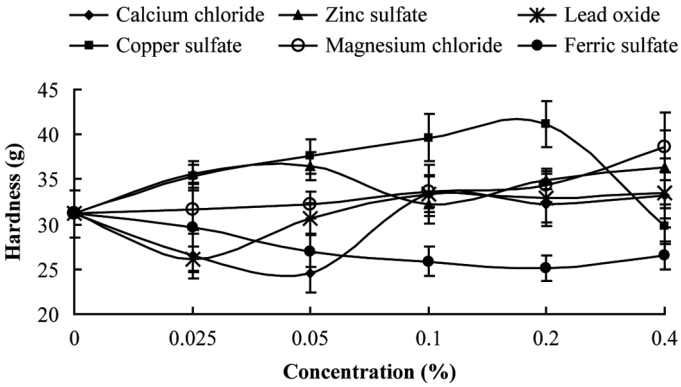

Figure 3. Effects of different metal salts on the strength of NaOH-induced egg white gel. The data were expressed as means ± SD.

Of the 6 metallic compounds, $CuSO_4$ (0.2%) exhibited the optimal effect on increasing the gel strength of alkaline-induced duck egg white, followed by $MgCl_2$ (0.4%), $ZnSO_4$ (0.05%), PbO (0.4%), and $CaCl_2$ (0.1%). By contrast, $Fe_2(SO_4)_3$ showed negligible effects on the gel strength. The effects of $CaCl_2$ and $Fe_2(SO_4)_3$ were not ideal, possibly because the concentrations used were not optimal. This result requires further confirmation in future experiments. The PbO is not soluble in water. Moreover, during gel sample preparation, yellow lead oxide precipitates were clearly found at the bottom of the beakers. Therefore, the effect of PbO on improving the gel strength of egg white was limited in this experiment.

During the preparation of preserved eggs, adding appropriate amounts of metallic compounds ensures that the products are of high quality. Lead oxide has traditionally been used to prepare preserved eggs. However, this compound is toxic. In recent years, copper, iron, zinc, and other metallic compounds have been used to replace lead. During preserved egg pickling, metallic compounds in the pickling solution are generally believed to form insoluble compounds that can plug eggshell and membrane pores and mesh the corrosion holes generated by alkali processing; these processes prevent the pickling solution from penetrating the egg, thus controlling the alkali content in the egg, which determine the egg white gel properties (Tu et al., 2013b). Several studies have shown that preserved eggs are difficult to prepare when only a ferric compound is added to the pickling solution (Yan and Zhu, 2006; Zhang et al., 2010). This finding is similar to our experiment result. Only the addition of zinc or copper compounds can yield preserved eggs with desired quality. Preserved eggs formed in the presence of zinc compounds have high yolk-hardening ratios. However, the gel properties of these eggs are unstable, and the gels are susceptible to alkali damage. By contrast, gels of preserved eggs prepared in the presence of copper compounds exhibited high elasticity and high stable stability but had low

yolk-hardening ratios. Methods involving the addition of copper and zinc compounds or the addition of iron and zinc compounds can create synergies during preserved egg preparation; this synergy yields preserved eggs with excellent protein gel characteristics (Yan and Zhu, 2006; Zhao et al., 2010). Solubility varies with the type of metallic compounds, therefore, differences exist in the control of preserved egg gel formation and gel characteristics. The solubility of iron in the pickling solution is initially negligible; the resulting insoluble material is insufficient to plug the eggshell pores. By contrast, the solubility of zinc in the pickling solution is initially higher, but the stability of its precipitate in the solution is also insufficient and results in low protein aggregation. The initial solubility of copper in the pickling solution and the stability of its precipitate lie between those of iron and zinc, which is beneficial for obtaining desirable protein gels of preserved eggs.

However, metallic compounds may serve other functions in the regulation of preserved egg gels, and thus require further investigation. As proposed by several researchers, divalent or monovalent cations can form polymers (Hongsprabhas and Barbut, 1997; Shi et al., 2008; Ganasen and Benjakul, 2011) with negative protein molecules via salt bridges, these polymers affect the gel formation of preserved eggs. The PbO_2, $ZnCl_2$, and $CaCl_2$ were also experimentally proven to increase the cohesiveness and hardness of preserved egg white gels. In addition, PbO_2 can stabilize several gel characteristics during egg maturation (Ganasen and Benjakul, 2011). This stabilization may be due to the close integration of lead with protein hydrolyzate cysteine residues through 3 thiol ligands, which results in the formation of polymers that are resistant to sulfhydryl hydrolysis.

Regardless of the mechanisms, the addition of metallic compounds is vital to the formation of preserved egg white and egg yolk gel formation and contributes to excellent gel characteristics. Although PbO is generally replaced by copper, zinc, iron, and other metallic compounds in commercial processes, excess amounts of metals, such as Cu and Zn, are also harmful to human health. Therefore, a method of preparing preserved eggs without adding metallic compounds is highly beneficial.

Effects of Different Carbohydrates on the Strength of NaOH-Induced Egg White Gel

Figure 4 shows the gel strength of egg white induced by 2.5% NaOH at 20°C for 105 min and with or without the addition of 0.025, 0.05, 0.1, 0.2, or 0.4% of different carbohydrate additives (glucose, sucrose, xanthan gum, sodium alginate, and starch). The addition of 0.025% and 0.05% sodium alginate reduced the gel strength of the egg white. When 0.1, 0.2, and 0.4% of sodium alginate were added, the gel strength gradually increased with increasing sodium alginate concentration. When the alginate sodium concentration was 0.4%, the gel strength increased by 40.64%. The addition of 5 concentrations of xanthan gum increased the gel strength. The 0.2% xanthan gum concentration was the optimum, and the gel strength increased by 54.31% compared with the control. Meanwhile, the addition of 0.025 and 0.1% starch reduced the gel strength. The addition of 0.05, 0.2, and 0.4% starch improved the egg white gel strength. The 0.4% starch concentration was the optimum, as indicated by the 10.91% increase in the condensate gel strength compared with the control. The addition of glucose increased the egg white gel strength. The 0.4% glucose was the optimum and resulted in 17.03% increase in the gel strength compared with that of the control. The addition of sucrose also increased the gel strength. The 0.4% sucrose concentration was the optimum and resulted in a 8.42% increase in the gel strength compared with the control.

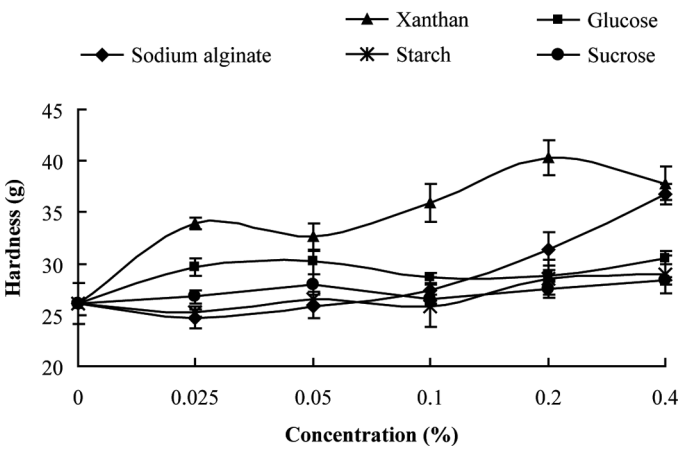

Figure 4. Effects of carbohydrates on the strength of NaOH-induced egg white gel. The data were expressed as means ± SD.

Figure 4 shows that the addition of xanthan gum, glucose, or sucrose increased the gel strength of NaOH-induced duck egg white at all concentrations used. When the sodium alginate and starch concentrations were below 0.05%, however, the gel strength was reduced. By contrast, the addition of sodium alginate and starch concentrations $\geq$0.1% gradually increased the gel strength as the concentration increased. Of the 5 carbohydrate additives, xanthan gum exhibited the optimal effect on increasing the gel strength of duck egg white, followed by sodium alginate, glucose, starch, and sucrose.

The effects of carbohydrate additives on the gel strength of duck egg white are highly complicated and their mechanisms are unclear. Among the carbohydrate additives used in the study, xanthan gum, sodium alginate, and starch were all polysaccharides. These 3 additives are generally used as thickeners, gelling agents, or film-forming agents to significantly improve the performance and quality of food (Xu et al., 2010). The addition of starch is reported to improve the quality of fresh egg gels (Tu et al., 2013a). In this study, the effect of

starch on improving the gel strength of NaOH-induced duck egg white was not satisfactory. The result may be related to the low solubility of starch in water and the gel preparation method. Additional studies should be conducted to address this issue.

Glucose is a reducing sugar, but sucrose is a nonreducing sugar. At the same level, the gel strength of the glucose groups was higher than that of the sucrose groups. The difference in the gel strength may be due to the higher protein content of egg white. Glucose can undergo glycosylation with the egg white protein, which results in covalent cross-linking between the proteins.

Effects of Stabilizers and Coagulants on the Strength of NaOH-Induced Egg White Gel

Figure 5 shows the effects of different stabilizers and coagulants on the NaOH-induced egg white gel strength. The addition of 5 concentrations of propylene glycol improved the gel strength of the egg white. The addition of 0.125 and 0.25% propylene glycol gradually increased the gel strength as the propylene glycol concentration increased. When the propylene glycol concentration reached 0.25%, the gel strength peaked and showed a 15.78% increase from the control value. The addition of 0.5 and 1% propylene glycol gradually reduced the gel strength. When the propylene glycol concentration reached 2%, the gel strength rebounded. Meanwhile, the addition of sodium phosphate dibasic increased the gel strength of the egg white. The lowest concentration of 0.125% and the highest concentration of 2% showed better effects than the control on increasing the gel strength by 11.99 and 12.35%, respectively. However, the addition of 0.125% GDL gel had a negligible effect on the gel strength. The gel strength slightly improved when 0.25% GDL was added, decreased when the GDL concentration reached 0.5%, and then rapidly increased upon the addition of 1 and 2% GDL. The GDL at 2% showed the highest gel strength as indicated by the 11.67% increase in the gel strength compared with the control. Of the 3 stabilizing agents and coagulants, propylene glycol showed the best effect on improving the gel strength of egg white protein, followed by sodium phosphate dibasic and GDL. These 3 additives all showed increasing trends in the high concentration used, suggesting that the addition of stabilizer/coagulant above would further improve the gel strength of egg white. Further studies should be conducted to prove this hypothesis.

Propylene glycol can reduce the dielectric constant of the aqueous medium and thus contribute to the hydrogen-bonding interaction of the proteins. Moreover, propylene glycol can form hydrogen bonds with protein molecules through the hydroxyl groups. Propylene glycol can also affect the molecular structure of water and prevent hydrophobic interactions, which would result in increasing egg white gel strength (Roussel and Cheftel, 1990). Meanwhile, sodium phosphate dibasic

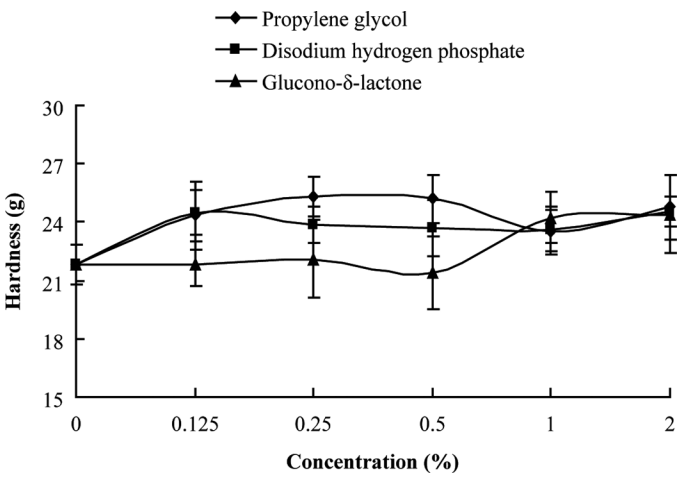

Figure 5. Effects of different stabilizers and coagulants on the strength of NaOH-induced egg white gel. The data were expressed as means ± SD.

can improve the function of the protein through phosphorylation (in which the phosphate group bonds with a specific oxygen or nitrogen atom of the proteins); phosphorylation introduces a phosphate group, which increases the electronegativity of the proteins and the dispersibility of the protein molecules (Ptacek and Snyder, 2006). Glucono-δ-lactone is produced from the cyclization of gluconic acid, which is formed by oxidized glucose molecules. Glucono-δ-lactone gradually hydrolyzes into gluconic acid until an equilibrium exists between gluconic acid and its δ-lactone and γ-lactone forms in aqueous solutions (Rahbar and Nadler, 1999). Glucono-δ-lactone is generally used as a coagulant of tofu and as a gelling agent and acidifier of milk. Studies show that the GDL-induced gelation of a soy protein isolate is the result of the reduction in the electrostatic repulsion between the negatively charged groups of the protein molecules (Kohyama et al., 1995). In the present experiment, the effect of GDL on the gel strength of egg white protein is not significant. This result is inconsistent with that reported in the literature (Kohyama et al., 1995), possibly due to the addition of NaOH during the egg white gel preparation and to the reaction temperature (20°C). These factors possibly directly affect the interactions between GDL and protein molecules. As a result, the effect of GDL on improving the gel strength of the egg white protein is not ideal.

Conclusions

The NaOH concentration and temperature clearly affected the strength of the egg white gel of preserved eggs. Moreover, the addition of the appropriate amount of additives, such as $CuSO_4$, xanthan gum, and propanediol, can improve the gel strength of egg white protein. However, several additives have negligible effects or weaken the egg white gel strength. Therefore, in practical applications of the current results, the type and amount of additives should be carefully se-

lected. The results also suggested that xanthan gum, sodium alginate, glucose, and propylene glycol could potentially be used as additives replacing metal compounds in processing of preserved egg. In our further work, these potential and useful additives will be added into pickling solution of preserved eggs to replace the metal compounds, and their effect on physicochemical, nutritional, and flavor characteristics of preserved eggs will be checked. At the same time, its safety also will be studied.

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