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Effects of freezing and thawing treatment on the rheological and textural characteristics and micro-structure of heat-induced egg yolk gels

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A B S T R A C T

The objective of this study was to evaluate the rheological, textural characteristics and micro-structure of heat-induced gels obtained from frozen-thawed egg yolk. Results indicated that egg yolk kept its ability to form heat-induced gels after being frozen and thawed. The textural characteristics of frozen-thawed yolk gels decreased when yolk/water ratio was reduced. The network development of frozen-thawed egg yolk gels was different from that of fresh ones. The elastic (G') and viscous (G'') modulus of frozen-thawed egg yolk started to increase at around 55 °C, and formed a stable network at about 90 °C. The addition of sugar did not affect the textural characteristics of the heat-induced gels from frozen-thawed egg yolk. However, the textural properties of gels improved significantly as the salt content was increased from 0 to 2% (w/w). In terms of the mechanical spectra and micro-structures, the crosslinking of heat-induced gels from frozen-thawed yolks was weaker than that of fresh egg yolk gels.

1. Introduction

Egg yolk possesses many nutritional components and important properties, such as emulsification and heat-induced gel forming ability (Anton, 2013; Kiosseoglou, 2003; Kiosseoglou and Paraskevopoulou, 2005). Fresh egg yolk (FEY) forms a firm gel structure if stirred before heating, quite different from the crumble structure due to direct cooking (Woodward and Cotterill, 1987a,b). Thus, egg yolk is widely used in many products, such as mayonnaise, cakes and puddings.

Egg yolk can be fractionated into its two main fractions, which is plasma and granules (Anton, 2013). Recent research showed that storaging fresh egg yolk at −20 °C over 10 h resulted in breaking of granules in yolk, as well as protein denaturation. Low density lipoproteins (LDLs) in plasma interact with the proteins released from granules, and then form gel-like egg yolk when the storage time is over 24 h (Au et al., 2015; Au et al., 2016; Kamat et al., 1976; Saari et al., 1964; Telis and Kieckbusch, 1997, 1998). The formation of the gel-like egg yolk by freezing and thawing treatment contributes to the increase in viscosity, reduction in fluidity, and decrease in emulsifying ability (Au et al., 2015; Chang et al., 1977; Telis and Kieckbusch, 1998), and consequently affects the application of egg yolk in food. Furthermore, freezing storage is a regular method in food industry due to its advantages of prolonging food shelf-life (Au et al., 2015). However, the ability to form heat-induced gels from egg yolk after freezing and thawing treatment is still unclear.

It was reported that the properties of heat-induced gels are related to the protein content, as well as salt added to the yolk (Raikos et al., 2007). Moreover, sodium chloride and sucrose were used to prevent the cold-gelation during egg yolk freezing (Telis and Kieckbusch, 1998). Therefore, factors that affect the textural properties of heat-induced egg yolk gels, such as protein content and sugar or salt concentration, were investigated in this study. The network development and mechanical spectra of frozen-thawed egg yolk (FTEY) gels were revealed. Furthermore, differences of micro-structure for the heat-induced gels from FEY and FTEY were compared.

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2. Materials and methods

2.1. Materials

Eggs were purchased from Beijing Changping Huilongguan market. All the reagents were of analytical grade.

2.2. Preparation of samples

The FEY and water were mixed at different ratios and frozen at −18 °C for 48 h. Subsequently, the yolks were thawed (FTEY) at room temperature before use. Only one cycle of freezing and thawing treatment was used.

To investigate how the different yolk-to-water ratios affected the textural characteristics of heat-induced FTEY gels, such a ratio was set to 1:0, 1:0.5, and 1:1 (w/w).

To evaluate how the textural characteristics of the heat-induced FTEY gels were affected by the sugar or salt concentration, the FEY and water were initially mixed using a ratio of 1:1, then frozen, and as soon as thawed, integrated with salt or sugar to an equal content of 1–4% (w/w).

The rheological properties of the heat-induced FEY and FTEY gels were assessed under a constant FEY/water ratio of 1:1.

2.3. Gel preparation

For the measurement of textural properties, the prepared FTEY or FEY sample was centrifuged for 10 min at 500×*g* (TD5A-WS Table-type Low-speed Centrifuge, Hunan Xiangyi Laboratory Instrument Development Co., Ltd., Changsha, China) in order to remove air bubbles, then poured into plastic syringes of 25 mL (20-mm diameter and 80-mm height), and sealed with plastic wrap. The plastic syringes were heated at 90 °C for 40 min as preliminarily assessed. After cooling, they were kept at 4 °C overnight and the resulting gels were used to analyze the textural characteristics and micro-structures.

As concerning the evaluation of the mechanical spectra of FEY or FTEY, the prepared blend (2.5 g) of FEY or FTEY (egg yolk:water = 1:1) was loaded into a plastic Petri-dish (diameter of 47 mm) and sealed with plastic wraps. After being heated at 90 °C for 40 min, the gels were cooled at room temperature and kept at 4 °C overnight. The gels were used for dynamic oscillatory measurement.

2.4. Texture analysis

The texture profile analysis (TPA) was carried out at ambient temperature with Brookfield CT3-1500 Texture Analyzer (Brookfield, US) equipped with a 6-mm cylindrical probe (TA41). The gels in the syringes were carefully released and cut into a few cylindrical samples (10-mm height and 20-mm diameter). Each sample was compressed axially in two consecutive cycles of 30% compression. The probe moved at a constant speed of 0.5 mm/s. From the TPA curves, the following texture parameters were obtained: hardness at 30% of deformation, springiness, cohesiveness. Hardness was defined as the peak force during the first compression cycle. Springiness was defined as the distance from start of second compression to the peak. Cohesiveness was calculated as the ratio of the area under the second curve to the area under the first curve.

2.5. Dynamic oscillatory measurement of yolk gels

The rheological properties of egg yolk gels were evaluated with a strain-controlled rheometer AR 1000-N (TA Instruments) equipped with a temperature controlling system. The gelation profiles of the samples were investigated by dynamic oscillatory measurements. Aliquots of the blend of FEY or FTEY with water at a ratio of 1:1 were transferred over the temperature-controlled Peltier surface of the rheometer, the latter being preheated at 25 °C. The sample was allowed to relax and equilibrate at the initial temperature (25 °C) for 2 min prior to assess its rheological properties. Gel formation was followed by heating the samples at a ramp rate of 5 °C/min from 25 to 95 °C. A 40 mm steel parallel plate with solvent trap geometry was used. The measuring gap between the plate and Peltier surface was 1 mm and the exposed edge was coated with a thin layer of mineral oil to prevent moisture loss. Preliminary experiments under different strain sweep tests showed that all samples behaved as linear viscoelastic solids under a strain of 0.1% at a fixed frequency of 1 Hz.

The mechanical spectra of such gels were determined by frequency sweep tests in the range of frequency of 1–100 Hz under constant sheer strain (0.1%) and room temperature. The measuring gap between the plate and Peltier surface was set as 3 mm because the plastic Peri-dish with gel (the thickness of the gel is 1 mm, and the thickness of the dish' bottom is 2 mm) was loaded on the Peltier surface of the rheometer. All tests were triplicated.

2.6. Soluble protein content measurement

FEY or FTEY were diluted using distilled water, and then centrifuged (4000×g, 20 min). A fraction (0.1 mL) of supernatant was mixed with 5 mL of protein reagent. The assay reagent was made by dissolving 100 mg of Coomassie blue G250 in 50 mL of 95% ethanol. The solution is then mixed with 100 mL of 85% phosphoric acid and made up to 1 L with distilled water. The reagent was filtered through Whatman No. 1 filter paper and then stored in an amber bottle at room temperature. Absorbance was measured at 595 nm by using an ultraviolet-visible spectrophotometer (Spectrum SP-2100, China). A 5-point standard curve was established using bovine serum albumin (BSA>98% pure, Sigma, US).

2.7. Scanning electron microscopy (SEM)

The FEY or FTEY gel curd was cut into small pieces (<2 mm cube) with a razor blade, and then immersed in 2.5% glutaraldehyde in phosphate buffer for 4 h. After that, the samples were rinsed 3 times with a phosphate buffer (0.1 mol/L, pH 7.2), and then dehydrated by using a series of ethanol-water solutions containing a volume fraction of ethanol equal to 30%, 50%, 70%, 90% and 100% (v/v). After that, the samples were freeze-dried. Dried samples were mounted on stubs and then sputter coated with gold. The microstructure of egg yolk gel was observed under SEM (Hitachi SU8010, Japan) at 3.0 kV.

2.8. Statistical analysis

All experiments were conducted three times. Analysis of variance (ANOVA) was conducted by the SPSS 18.0, and significant differences between group means were analyzed by Duncan multiple range test ($P < 0.05$).

3. Results and discussion

3.1. Textural properties of heat-induced FEY and FTEY gels

The textural characteristics of the heat-induced gels obtained from FEY and FTEY are shown in Table 1. As the egg yolk concentration decreased from 100 to 50% (w/w), the hardness of both FEY and FTEY gels significantly reduced. Whereas, the elasticity of the