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High pressure modification of egg components: Exploration of calorimetric, structural and functional characteristics

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ABSTRACT

The effects of high pressure (HP) treatment on the thermal, rheological and functional properties of various egg components (whole liquid egg and liquid egg white) were studied as a function of increasing pressure level and treatment time. Differential scanning calorimetry (DSC) and rheometric analysis were utilized to evaluate the extent of protein denaturation and liquid-gel transformation details (G′, G″). Overall, HP-treated samples exhibited predominantly solid-like (G′ > G″) behavior in the frequency range employed (0.1–10 Hz). Pressure level (350–550 MPa) and treatment time (5–15 min) contributed significantly towards modification of liquid samples to partial gel formation. The highest level of pressure treatment (550 MPa for 15 min) was sufficient to cause complete gelatinization. Egg components exhibited a gradual liquid–solid gel transformation as they coagulated/denatured. Corresponding changes were observed in the flow behavior with increasing consistency behavior (m value) and decreasing flow behavior index (n value) showing pseudoplastic behavior. Functional properties like foaming ability, color and viscosity changed with alteration of rheological/structural properties for liquid egg white; however, whole liquid egg showed fewer significant changes ($p < 0.05$).

Industrial relevance: Egg is known as a multifunctional food ingredient, and it plays a significant role in improving the functional profile of other finished foods. High-pressure processing can change the flow behaviour and structure by causing denaturation of proteins. These structural changes further induce transformation in the functional behavior of eggs like color, foaming and viscosity that is of prime importance in the food industry. Hence, evaluation of pressure processing conditions for modifying the egg functionality will help in developing egg and egg products with improved functionality.

1. Introduction

Food proteins possess a broad range of functional properties, and food technologists always seek proteins with versatile and broad spectrum functionality. There have been attempts to seek proteins from more economical sources, to extend traditional food and to develop food with new functional ingredients (Mine, 2007; Kassis, Drake, Beamer, Matak, & Jaczynski, 2010; Tolin et al., 2012). Egg is known as a multifunctional ingredient, and it fits all of the above-mentioned requirements. It is known for excellent foaming, gelling and emulsifying characteristics and these are used in the food industry for a variety of applications (Mine, 1995; Zheng et al., 2015). Improvement of functional properties can be done by modifying the structure by physical, chemical or enzymatic methods (Kato, Osako, Matsudomi, & Kobayashi, 1983; Arai, Watanabe, Dickinson, & Stainsby, 1988; Monfort et al., 2012; Van Buggenhout et al., 2015). This enhancement can impart desirable features including appearance, texture, and consistency to a broad range of food products (Mine, Noutomi, & Haga, 1990; Molina, Papadopoulou, & Ledward, 2001; Manzocco, Panozzo, & Nicoli, 2013).

The traditional thermal processing method can cause denaturation and thus result in alteration of functional properties. There have been many studies regarding alterations caused by heat in structural properties which in turn modify functional properties of egg proteins (Donovan, Mapes, Davis, & Garibaldi, 1975; Mine et al., 1990; Van der Plancken, VanLoey, & Hendrickx, 2006; Ma, Lozano-Ojalvo, Chen, Lopez-Fandiño, & Molina, 2015). Heating of egg white solution in the temperature range of 50–85 °C results in significant unfolding of the proteins as shown by sulfhydryl (SH) groups and higher sensitivity towards proteases. These alterations are expected to change foaming characteristics of the treated egg white (EW) solutions (Van der, Plancken, VanLoey, & Hendrickx, 2007; Manzocco et al., 2013).

High-pressure processing (HPP) has been always investigated as an alternative to the traditional thermal processing. It can cause enhancement of functional properties of food proteins (Vanga, Singh, & Raghavan, 2015) in addition to microbial (Karataş & Ahi, 1992) and

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enzymatic inactivation (Knorr, Heinz, & Buckow, 2006). Thus, it helps in achieving enhanced functionality in addition to safe food. It can cause modification of the quaternary and tertiary structure of a protein that can lead to denaturation, aggregation and gelation (Balny & Masson, 1993; Cheftel, 1995; Li, Wang, & Liao, 2014) which can result infood products with improved texture and better mouth feel. High-pressure processing is a complex process, and it involves the formation of hydrogen and disruption of hydrophobic bonds (Heremans, 1982; Lametti et al., 1998; Silva, Villas-Boas, Bonafe, & Meirelles, 1989). Modification of protein structure by pressure treatment could lead to the enhancement of the surface properties and functionality. Functional properties of proteins have a direct relationship with the structure of proteins (Ahmed & Ramaswamy, 2003; Ahmed, Ramaswamy, Ayad, All, & Alvarez, 2007; Ramaswamy, Singh, & Sharma, 2015). Hickson et al., 1982 measured changes in gel characteristics due to protein modification of egg albumen by heat treatment and found that the viscosity increased in correlation with functional properties like elasticity and gel strength during storage of eggs. HPP can cause a number of changes in the viscoelastic behavior of a protein that in turn affects the functional properties (Ahmed, Ramaswamy, Alli, & Ngadi, 2003; Ahmed, Ramaswamy, & Raghavan, 2008).

HPP causes a smaller effect on surface hydrophobicity in comparison to elevated temperature. Contrary to temperature, the decrease of exposed SH groups due to SH oxidation is enhanced by pressure (Van der Plancken et al., 2006). These observations explain the reason, why pressure-induced protein solubility causes lower loss of functionality as compared to heat treatment. Pressure induced structural changes in egg white proteins can also be demonstrated by the exposure of buried hydrophobic and SH groups resulting in increased flexibility (Lametti et al., 1998; Lametti et al., 1999; Van der Plancken, VanLoey, & Hendrickx, 2005).

Pressure-induced changes in protein structure will affect the foaming and functional characteristics of pressurized egg solutions. It has been known that moderate unfolding of egg white using even a simple pH-induced unfolding and refolding regime could significantly improve its foaming properties (Liang & Kristinsson, 2005). The foaming properties of heat and pressure treated egg white are different because the mechanism of protein denaturation by heat and pressure are dissimilar (Van der Plancken et al., 2005). There have been numerous studies conducted on the pressure-induced gelation of egg white (Bridgman, 1914; Hayashi, Kawamura, & Nakasa, 1989; Balny & Masson, 1993; Hoppe, Jung, Patnaik, & Zeece, 2013); however, none of these studied functionality changes in depth. In this study, the effect of pressure level on viscoelastic and flow properties have been investigated and the changes in the denaturation, color, viscosity and foaming changes of both EW and whole liquid egg (WLE) have been correlated. This study will play a significant role in defining the role of specific pressure treatements to be used based on the intended role of egg components in food formulations; for example low level treatments help to enhance certain color, foaming and flow properties of the liquid egg while higher pressure – time combinations are desired for improving textural properties.

The objective of this work is evaluate the effects of increasing pressure level (350–550 MPa at constant time of 5 min) and increasing treatment time (550 MPa from 5 to 15 min) on the viscoelastic, thermal behavior and other functional properties of EW and WLE.

2. Materials and methods

2.1. Sample Preparation

Grade A chicken eggs were purchased from a local market and were broken manually to carefully separate egg white from the yolk using the Harrison and Cunningham (1986) preparation method. Whole liquid eggs (WLE) were prepared by mixing egg ingredients using a manual egg beater at a slow speed to avoid any damage to egg structure. Egg samples were prepared and poured into flexible 2 oz. Nasco polyethylene bags (Whirl Pak®, Nasco, Fort Atkinson, WI, USA) (10 mL per pouch) and sealed. Samples were treated immediately with high-pressure processing.

2.2. High-pressure treatment

Samples were processed using an ACB France (ACIP 6500/5/12VB; ACB Pressure Systems, Nantes, France) high-pressure processing unit. Pressurization and depressurization rate were maintained at default settings (4.4 MPa/s and 26 MPa/s) respectively. Samples were processed for increasing pressure level (350–550 MPa) for a constant time and increasing time (5 to 15 min) at a constant pressure of 550 MPa (Table 1). The high-end conditions (550 MPa 5–15 min) in this work were designed to meet pasteurization applications. The commercial practice used for pasteurization of food products involves the application of pressure ranging from 550 to 650 MPa. There was a possibility for the temperature to increase during pressure treatments, by 10–15 °C depending on the pressure level used. The treatment temperatures were nearly 20 °C with a small rise of ~5 °C at the commencement of the first run (discarded), but equilibrating to 20 °C on completion. The liquid in the chamber would cool by an almost same margin following the pressure release (resulting in the liquid temperature of ~15 °C). This process helped to maintain the process temperature ~20 °C for all remaining test runs. All the experiments were carried out in duplicates.

2.3. Viscoelasticity

HPP samples (2 ml) were transferred to a controlled stress rheometer (AR2000 series rheometer, TA Instrument, New Castle, DE, USA) and measured for changes in viscoelastic behavior. A $2^{0°}$ cone (6 cm diameter) geometry was used with a gap width of 1000 μm. The temperature used during measurement was 22 °C, which was maintained using a circulating bath and a controlled Peltier plate system. Linear viscoelastic region (LVR) was determined by performing the stress sweep tests at the frequency of 1 Hz. Frequency sweep tests (0.1–10 Hz) were carried out in the linear regime at 22 °C. The experimental rheological data was obtained directly from the TA Rheology Advantage Data Analysis software V 5.1.42 (TA Instruments, New Castle, DE, USA). The deviation did not exceed 5% between duplicate runs. All rheological measurements were carried out in duplicates.

2.4. Flow Behavior

The flow behavior of egg components was evaluated using a stress-controlled rheometer. Flow behavior index and consistency coefficient were best fitted using the power law model:

$$\mathrm{n} = \mathrm{mY}^{\mathrm{n}-1} \tag{4}$$

where n is known as the flow behavior index which is a dimensionless quantity. The consistency coefficient, m, (Pa-s^n), describes the overall viscosity range of the flow curve.

Table 1
Experimental plot to evaluate effect of high pressure processing and treatment time on viscoelasticity and functional properties.

Pressure (MPa)	350	450	550
Time (min)	5	5	5
	X	X	10
	X	X	15