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Rheological properties and protein quality of UV-C processed liquid egg products

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ABSTRACT

Rheological properties define the functionality and consequently, the technological quality, of food proteins. This study deals with the effects of short-wave ultraviolet treatments (dynamic or static UV-C) on the dynamic viscosity, flow behaviour, temperature-dependent viscosity, thermal properties and electrophoretic patterns of liquid egg products. Remarkably, none of the investigated parameters have been significantly influenced by UV-C treatments, static or dynamic. Rheological data, and thermal and electrophoretic properties indicate that the flow behaviour of UV-C treated egg white, whole egg or egg yolk, has not varied, and relevant protein denaturation or aggregation could be discarded. On the contrary, heat pasteurizations caused an increase on the viscosity-shear rate dependency, and also a certain degree of coagulation could be observed in the flow behaviour diagrams. Pasteurization additionally caused a reduction on the denaturation enthalpy observed in temperature-dependence viscosity measurements, and in DSC thermograms. The electrophoretic profiles also confirmed a certain degree of denaturation after pasteurization, with a reduction in the amount and intensity of the observed proteins. These results indicate that UV-C treatments do not affect significantly the rheological properties and the protein profile of liquid egg fractions, and could be used as an alternative to pasteurization.

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1. Introduction

Eggs, in particular chicken eggs, are recognized as a basic foodstuff for humans due to their high protein content and low cost, being the mass production of chicken eggs a worldwide industry (Li & Zhang, 2005; Yang, Li, Zhu, & Zhang, 2009). In addition, liquid egg fractions (egg white and egg yolk) possess highly desirable functional and nutritional properties. They are an adequate source of all essential amino acids, many vitamins, and important minerals (Souci, Fachmann, & Kraut, 2008). In addition, egg white proteins are well known for their gelling, foaming, and emulsifying properties (Li & Zhang, 2005; Min et al., 2005).

Heat induces the oxidation of egg proteins leading to changes in the sulphydryl content, and specifically the unfolding of ovalbumin and other egg white proteins, resulting in the modification of the functional properties and finally, in coagulation (Lai et al., 2010; Van der Plancken, Delattre, Van Loey, & Hendrickx, 2004; Van der Plancken, Van Loey, & Hendrickx, 2006; Van der Plancken, Van Remoortere, Van Loey, & Hendrickx, 2003). For instance, ovalbumin contains four sulphydryl groups buried in the protein core and one disulfide bond, being the strength of the gels formed during heating strongly related to the decrease in the amount of the total sulphydryl groups (Hayakawa & Nakai, 1985). In egg yolk, the interaction between thermally unfolded livetins and the partially denatured low-density lipoprotein (LDL) increases the viscosity (Jaekel & Ternes, 2009), and finally originates protein aggregation. Consequently, the characterisation of the physicochemical properties and the flow behaviour of liquid egg products is particularly relevant to evaluate the egg functional properties after processing, and has been the subject of several studies. Punidadas and McKellar (1999) investigated the rheological properties and the density of liquid egg products at pasteurization temperatures, and reported that all of them show shear-thinning behaviour, which can be described by the Power-Law model. Telis-Romero, Thomas, Bernardi, Telis, and Gabas (2006) showed that egg yolk is pseudoplastic between 4 and 60 °C. The protein profile was studied by means of SDS-electrophoresis (Van der Plancken, Van Loey, & Hendrickx, 2005).

Eggs are highly susceptible to microbial contamination, and liquid egg products must be processed to guarantee their safety. Normally, heat pasteurization is required to control pathogenic microorganisms, and specifically *Salmonella* species, in liquid egg products (USDA-ARS 74-48, 1969). For this, temperatures around 60 °C are recommended, which fall in the range causing protein unfolding and the subsequent formation of insoluble aggregates. In this context, short-wave ultraviolet treatments are emerging as an

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attractive non-thermal alternative to conventional thermal processing. UV-C (short-wave ultraviolet) treatments with germicidal lamps are currently being profusely investigated because they are recognized to be very effective to decrease the risks associated to microorganisms, and to extend the food shelf-life with a minimal impact in the food physicochemical attributes (Koutchma, Kellerb, Chirtelc, & Paris, 2004; Schmidt & Kauling, 2007). The effects of UV-C on liquid egg products have been investigated mainly to evaluate the level of microbial inactivation. This has been found to depend mainly on the optical density of the product, the initial microbial load and the liquid depth (Unluturk, Atilgan, Baysal, & Tari, 2008; Geveke, 2008). In addition, some works concentrate on the effects on the physicochemical characteristics of liquid egg products. For instance, De Souza and Fernandez (2011) concluded that UV-C does not cause considerable changes in the colour or the pH in egg yolk or egg white, but it was a non-negligible factor increasing the oxidation of fatty acids. And Kuan, Bhat, and Karim (2011) suggest that UV-C treatments induce a certain degree of protein cross-linking which improves the foaming ability of egg white.

In the present study, we compared the effects of heat or UV-C treatments on the flow behaviour and the temperature-dependent viscosity, on the thermodynamic properties and the solubility of the proteins of egg white, whole egg and egg yolk. Those parameters are strongly related to the egg functional properties (gelling, emulsifying and foaming), and consequently they can be considered as key factors describing the technological quality of liquid egg products.

2. Material and methods

2.1. Materials

Fresh eggs were purchased from Avícola Llombay (Valencia, Spain). They were of yellow shell, and weighted between 55 and 61 g. After reception, eggs were inspected for shell integrity and stored under refrigeration at 8 °C. Just before experiments were carried out, the egg content (separately, egg whites and egg yolks) was removed under aseptic conditions, and collected in sterile containers. The pH of the samples was controlled before proceeding with the experiments and eggs were considered to be fresh when pH were around 7.2 (±0.2) for egg white, and 6.2 (±0.2) for egg yolk. The chalaza was removed and the separated egg fractions were then homogenized for 1 min using a vortex (MS3 Digital, IKA®, USA), at the maximum speed (3000 rpm). To prepare the whole egg samples, 13.3 mL of egg yolk were mixed with 26.7 mL of egg white.

2.2. Methods

2.2.1. UV-C irradiation of egg samples

Following Bhat, Ameran, Voon, Karim, and Tze (2011), UV-C irradiation at germicide wavelengths of liquid egg samples was conducted in batch in a UV bench scale chamber designed by UV-Consulting Peschl® España (Burjassot, Valencia, Spain) with dimensions 55 × 35 × 55 cm. The chamber is provided with one low pressure mercury lamp with 7.3 W output, 436 mm length (Heraeus Noblelight GmbH, Hanau, Germany), and maximum peak radiation at 253.7 nm. Samples (12 mL volume; 0.2 cm height) placed in sterile polystyrene 60.3 cm^2 Petri dishes, were treated up to 30 min under static or dynamic conditions (when no relevant differences are observed, only results after 30 min are shown). Samples were situated at 10 cm from the lamp. For the dynamic treatment, samples were continuously stirred during irradiation at 400 rpm (Ovan MBG15, Barcelona, Spain). Samples were treated at room temperature (approx. 20 °C). Under similar conditions, an average fluence of 2.4 mW cm^{-2} was estimated by actinometry with the same lamp (Corrales, Souza, Stahl, & Fernandez, 2012), resulting in a final dose of approximately 4.2 J cm^{-2} after 30 min treatment.

2.2.2. Pasteurization

Aiming at a comparison with conventional pasteurizations, 1 mL ampoules of the analyzed egg fractions were treated using a thermostatic bath (Unitronic OR, Selecta, J. P. Barcelona, Spain) set to 56.6 °C, 60 °C and 61.1 °C respectively for egg white, whole egg and egg yolk. The conditions for pasteurisation were chosen in conformity with the requirements of the USDA (USDA ARS 74-48, 1969). The holding time used for the three fractions were of 3.5 min when the coldest point of the sample attained the pasteurization temperature.

2.2.3. Assessment of microbial loads

Total aerobic counts were evaluated on Plate Count Agar (PCA, Scharlau, Germany) after serial decimal dilutions in 0.1% peptone water using a pour plate technique. Mesophilic microorganisms (MEC) were incubated at 30 °C for 48 h and enumerated.

2.2.4. Rheological properties

2.2.4.1. Viscosity measurement as a function of shear rate. Viscosity measurements as a function of shear rate were carried out following the method described by Severa, Nedoma, and Buchar (2010). Apparent viscosity, which is the ratio of shear stress and shear rate (Steffe, 1996), of liquid egg fractions was measured using a rheometer (Rheostress RS100, Haake, Karlsruhe, Germany), equipped with a parallel-plate measuring system (rotor 222-1223, 35 mm radius, 1.0 mm gap). Samples were examined at room temperature (~20 °C). Measurements were carried out with an increasing shear rate (0.17–68 s^{-1}). The duration of the experiment was set up to 10 min.

Data were adjusted by linear regression to the power-law model:

$$\eta = K\dot{\gamma}^{n-1} \tag{1}$$

where η is the viscosity, $\dot{\gamma}$ is the shear rate, K is the consistency coefficient and n is the power-law index.

2.2.4.2. Time-dependent viscosity. Rheological measurements were made as described by Lee, Heinz, and Knorr (1999), in a rheometer (Rheostress RS100, Haake, Karlsruhe, Germany), equipped with a parallel-plate measuring system (rotor 222-1223, 35 mm radius, 1.0 mm gap), which was controlled to be 20 °C by a Thermo Haake C25P refrigerated bath (Karlsruhe, Germany). Samples were sheared for 5 min at a fixed rotational speed of 55 rpm (corresponding to a Newtonian shear rate of 300 s^{-1}). During the shear, torque was recorded every second by the data acquisition software Rheowin Pro (v. 3.61, Haake, Karlsruhe, Germany). The excess work of structure breakdown (ΔW), or degree of coagulation, is proportional to the area under the stress overshoot peak:

$$\Delta W = \dot{\gamma} \int (\tau - \tau_e)\, dt \tag{2}$$

where $\dot{\gamma}$ is the shear rate, τ is the shear stress, τ_e is the equilibrium shear stress.

2.2.4.3. Temperature-dependent viscosity. The temperature-dependent viscosity measurements were carried out using a rheometer (Rheostress RS100, Haake, Karlsruhe, Germany), equipped with a parallel-plate measuring system (rotor 222-1223, 35 mm radius,

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