Innovative Food Science and Emerging Technologies 32 (2015) 156–164

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Functional properties and nutritional composition of liquid egg products treated in a coiled tube UV-C reactor

Poliana Mendes de Souza [a,b,1], Alexandra Müller [b], Adnane Beniaich [d], Esther Mayer-Miebach [b], Kathleen Oehlke [b], Mario Stahl [b], Ralf Greiner [b], Avelina Fernández [a,c]

[a] Department of conservation and quality, Consejo Superior de Insvestigaciones CientíficasInstituto de Agroquímica y Tecnología de Alimentos,Avda. Agustín Escardino, 7, Paterna 46980, Spain
[b] Department of Food Technology and Bioprocess Engineering, Federal Research Institute of Nutrition and Food, Max Rubner-Institut,Haid-und-Neu-Str. 9, Karlsruhe 76131, Germany
[c] Instituto de Física Corpuscular, Consejo Superior de Investigaciones Científicas–Universitat de València, Parc Científic, Paterna, Valencia 46980, Spain
[d] Departamento de Ciência do Solo, Universidade Federal de Lavras, Av. Doutor Sylvio Menicucci, 1001-Kennedy, Lavras, MG 37200-000, Brazil

ARTICLE INFO

Article history:
Received 13 June 2015
Received in revised form 10 September 2015
Accepted 12 September 2015
Available online 26 September 2015

Keywords:
Ultraviolet
Liquid egg
Vitamins
Functional properties
Foaming
UV-C
Dean vortex

ABSTRACT

Pasteurization of eggs has adverse effects on nutrient composition and functionality of egg proteins. UV processing is an alternative technology with potentially fewer adverse effects as it is less intrusive. Egg white, whole egg and egg yolk vitamins (A, B_2, B_5, C and E), minerals (P, Cl, K, Na, Ca, Mg, Fe and Zn) and main secondary metabolites (lutein and zeaxanthin) were examined after exposure to UV in a coiled tube UV-C reactor at doses known to achieve microbiologically stable egg fractions. The studied nutrients were fairly stable to a treatment with UV-C light with the exception of retinol, vitamin C and carotenoids, which showed loses up to 80%, 66% and 61%, respectively. Moreover, the functional properties of ultraviolet-treated eggs were investigated. Results showed a positive impact on the foam ability and foam stability, and an increase on the emulsifying activity index above 20% versus pasteurized samples. Processing with UV can maintain most of the egg nutritive properties, and retain or even improve the technological properties of foaming and emulsification in eggs.
Industrial relevance:: This novel UV-C system can be applied successfully to the Food Industry.
UV-C does not impair nutritional damage to egg-treated products, and even improve egg functional properties.
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1. Introduction

Poultry products contribute significantly to the vitamin intake of consumers. Eggs are one of the most common daily foods, naturally contain nine essential vitamins, and represent an important source of phosphorus and iron. The egg has also been described as a low energy source of equilibrated proteins and easily digested fats. Besides, hen egg is a multifunctional ingredient widely used in many food preparations.

Eggs are an excellent substrate for spoilage related microorganisms and food-borne pathogens, and they are a highly perishable product, even under refrigeration. Egg products need to be pasteurized to extend shelf-life and to lower consumer risks associated to food-borne microorganisms such as *Salmonella*. Thermal pasteurization is the most extensively applied method in order to prevent food spoilage. On the other hand, thermal treatments may have a negative effect on egg functional and physicochemical properties, as well as on the nutritional value or the sensory attributes, which make them less attractive in terms of colour and texture (Falguera, Garza, Garvín & Ibarz, 2011).

Non-thermal processes might be an excellent alternative to overcome the problems associated to the changes in egg functional properties. Similar to thermal pasteurization, non-thermal pasteurization of eggs is challenging and despite substantial efforts, and none of the non-thermal technologies has been commercialized for liquid egg products. These processes include pulsed electric fields (Amiali, Ngadi, Raghavan & Smith, 2006), electron beam radiation (Wong, Herald & Hachmeister, 1996), as well as gamma radiation, and high hydrostatic pressure (Andrassy et al., 2006).

The use of UV-C is well established for water treatment, air disinfection and surface decontamination (Butz & Tauscher, 2002; Koutchma, Keller, Chirtel & Parisi, 2004; Noci et al., 2008), and some works already report the efficient inactivation of inoculated microorganisms in liquid egg products (Geveke, 2008; Souza & Fernández, 2011; Unluturk, Atilgan, Baysal & Unluturk, 2010). As a physical preservation method, UV irradiation has a positive consumer image and was approved by the US Food and Drug Administration (FDA) for the treatment of clarified juice products (US FDA, 2000). Few data are still available on the effect of this technology on the nutritional composition and functional properties of foods, but some of them point out for the variability of the food matrices and the necessity of detailed research works.

E-mail address: poliana.souza@ict.ufvjm.edu.br (P.M. de Souza).
[1] Tel.: +55 38 98,070,903; fax: +34 963,636,301.

http://dx.doi.org/10.1016/j.ifset.2015.09.004
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Whited, Hammond, Chapman and Boor (2002) studied the effects of UV-C on the vitamin A content in skimmed, semi-skimmed and whole milk, concluding that fat had a protective effect on the degradation of this vitamin; in all cases, it was observed, apart from the loss of this vitamin, a loss of milk quality because of poor sensory results, highlighting off-flavours. Furaya, Warthesen and Labuza (1984) studied the photodegradation of riboflavin in macaroni, skimmed milk powder and buffer solutions. In liquid systems, those authors found first-order photodegradation kinetics, while in solid food systems a two-step mechanism was observed. Milliken Chemical has conducted UV exposure testing on several vitamins, including A, B_2 (riboflavin), B_6, B_{12} and folic acid in fruits and/or buffered media. In general, each of those showed substantial sensitivity to UV. The effect of UV-C light on ascorbic acid is generally negative; it decreases immediately after illumination in pineapple, banana and guava (Alothman, Bhat & Karim, 2009).

UV-C induces a non significant protein damage, characterized by the total sulfhydryl group reduction and induces oxidative modifications in egg preparations however do not cause any increase in the cyto- or genotoxic (DNA strand breaks) effects in intestinal Caco-2 cells (Souza, Briviba, Müller, Fernández & Stahl., 2013). 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 (Souza et al., 2013). Previous studies indicate that egg and egg preparations are stable matrixes when UV-C processing was applied.

The purpose of this study was to determine the effects of a semi-continuous treatment in a coiled tube UV-C reactor on vitamins, carotenoids and mineral content in liquid egg products, and furthermore to study the changes in egg relevant technological properties at conditions necessary to achieve a pasteurization with UV-C treatment.

2. Material and methods

2.1. Egg samples

Brown hen's eggs, weighing between 55 and 61 g from in cage hens laid between March and June, were purchased from a local supermarket at Karlsruhe, Germany. After reception, eggs were inspected for shell integrity and stored at 4°C until further processing within 2 weeks.

2.2. UV-C radiation of egg samples

Egg whites and egg yolks were removed separately under aseptic conditions, collected in sterile containers and homogenized each for 1 min using a commercial blender (31BL44, Waring, USA), at maximum speed. Whole egg samples were prepared from homogenized egg yolk and egg white by mixing in a ratio of 1:2.

UV-C radiation experiments were conducted using the UVivatec Lab® reactor (Bayer Technology Services GmbH, Germany) equipped with Teflon tubing (PTFE) helically coiled around a low-pressure mercury lamp emitting UV light with maximum emission peak at 254 nm and 9 W output power. Egg samples were passed through the reactor at different flow rates (9.5, 14.5 and 2.6 L h^{-1} for whole egg, egg white and egg yolk, respectively) using a peristaltic pump. The dose exposure depends on the rate, irradiation intensity, sample characteristic such as absorbance and turbidity and the flow field (Huch et al., 2010; Franz, Specht, Cho, Graef & Stahl, 2009; Schmidt & Kauling, 2007). Doses applied reached 20.1 J L^{-1} for egg white, 32.2 J L^{-1} for whole and 115.6 J L^{-1} for egg yolk, based on previous studies of microbial inactivation in the same equipment (Souza, Müller, Fernández & Stahl, 2014. Table 1 shows the physical parameters characteristic for the liquid egg fractions and Table 2 gives an overview of the doses.

Table 1
Physical properties of the egg fractions ± standard deviation (SD). Results are the mean of three replicates.

	Egg white	Whole egg	Egg yolk
Optical density at 254 nm	42.03 ± 3.67	730.67 ± 65.85	1266.67 ± 135.77
Turbidity (NTU)	276.24 ± 22.64	9128.05 ± 1475.80	10,827.89 ± 136.89
Viscosity (mPa s)	3.90 ± 0.28	8.17 ± 0.04	86.95 ± 4.63
Density (g cm^{-3})	1.0414 ± 0.0015	1.0354 ± 0.0025	1.027 ± 0.0050

2.3. Analysis of functional properties

2.3.1. Foaming properties

Foaming properties were determined using the method described by Song et al. (2009) with modifications described by Kuan, Bath and Karim (2011). Briefly, egg samples were dissolved to 1% *w*/*v* in water. Aliquots of 30 mL each were aerated using an Ultra-Turax T25 basic (IKA-Werke, Staufen, Germany) for 1 min at 25°C and 12,000 rpm within a graduated cylinder to estimate liquid volumes before and after aeration. The foaming activity was calculated from the volume increase in relation to the initial volume (% volume). Foam stability was expressed as percent liquid drainage in relation to the initial liquid volume after a holding time of 30 min, according to Eq. 1:

Where V_{PF} is the volume of prepared foam, V_{LD} is the volume of liquid drainage, and V_{OL} is the original volume of liquid.

$$\%V = (V_{PF} - V_{LD})/V_{OL} \times 100\% \quad (1)$$

2.3.2. Emulsifying properties

The emulsifying activity index (E_{AI}) for treated/untreated samples was determined according to the method previously described by Pearce and Kinsella (1978) based on turbidity (T) measurements. For this, emulsions were formed by homogenizing (Ultra-Turax T25 basic, KA-Werke, Staufen, Germany) 3.0 mL of a sample solution (0.1% (*w*/*v*) in 100 mM sodium phosphate buffer, pH 7.4) with 1.0 mL sunflower oil for 1 min at 25°C and 12,000 rpm. Aliquots of 100 μL of the emulsion were taken from the bottom of the test tube directly as well as up to 20 min after emulsification. Each sample was diluted immediately with 5 mL of SDS (0.1% (*w*/*v*) in 100 mM sodium phosphate buffer, pH 7.4) and absorbance (A) measured at 500 nm (UV2, Unicam, Germany). The emulsifying activity index (E_{AI}) was calculated according to Eq. 2.

$$E_{AI} = 4.606 \times A \times P_W \quad (2)$$

where *A* is the absorbance and P_W is the protein weight on the sample.

2.4. Lipid oxidation

To evaluate the extension of the lipid oxidation, the determination of the amount of the formed 2-thiobarbituric acid-reactive substances (TBARS) was undertaken according to Vynckel (1970) and Ramanathan and Das (1992), previously adapted by Souza and Fernández (2011). In brief, the samples were freeze-dried in a Genesis Freeze Dryer (SP Virtis, 35EL Genesis SQEL85, New York, USA). Then 2.5 g of the dry samples was mixed during 10 min with 17 mL of 7.5% (*w*/*v*) trichloroacetic acid (TCA), then filtered with a cellulose filter in a 10 mL volumetric flash. Volume (up to 10 mL) was filled up with 7.5% TCA solution if necessary. Equal volumes of the filtered solution and 0.02 M thiobarbituric acid (TBA) were then mixed and heated in a boiling water bath (Unitronic OR, Selecta, Spain) for 40 min. Samples were allowed to cool down until they reached room temperature. TBARS index was estimated in a spectrophotometer (Agilent, St. Claire, USA) at 530 nm. Concentrations of TBARS were determined using a

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