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Microbiological efficacy in liquid egg products of a UV-C treatment in a coiled reactor

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ABSTRACT

The feasibility of ultraviolet processing as a non-thermal pasteurization technique for liquid egg products was investigated. Inactivation of *Salmonella subterranea* DSM 16208 followed comparable kinetics than *Salmonella enteritidis*, therefore it was used as a non-pathogenic surrogate. The influence of the dose on the inactivation of *S. subterranea* DSM 16208, *Escherichia coli* DH5α and *Listeria innocua* WS 2258 in liquid egg fractions was evaluated on a laboratory scale recirculating UV-C treatment coiled reactor UVivatec® Lab (Bayer Technology Services GmbH, Leverkusen, Germany) and a higher scale laboratory device (coiled tube reactor MRI2010, designed and assembled at the Max Rubner-Institut, Karlsruhe, Germany). Analogous inactivation kinetics were observed for all microorganisms, in which inactivation curves followed a logarithmic decay and changed over to a tailing phenomenon after some time of UV-C exposure. Comparable inactivation behavior and doses to inactivate the selected microorganisms were detected for whole egg, flowing from 9.5 to 20 L h^{-1}. Highest doses were necessary to attain a 5 Log reduction on egg yolk. UV-C processing resulted in a shelf life extension of liquid egg up to 8 weeks at 4 °C, which corresponds to a storage period 4 times higher than the recommended for pasteurized LWE.

Industrial relevance: This novel UV-C system can be applied successfully to the Food Industry. UV-C can be effectively used to reduce the number of spoilage and pathogenic bacteria, as well as yeasts and molds in different kinds of food products.

1. Introduction

Novel food processing technologies include the use of physical factors to process and preserve food. Most of them, such as high hydrostatic pressure, pulsed electric fields, cold plasma, ultrasound/cavitation, and ultraviolet light, are non-thermal or operate at temperatures below conventional heat treatments. Among them, ultraviolet technology at germicidal wavelengths (UV-C) has shown perspectives for the pasteurization of liquid food products in appropriate designed reactors (e.g. Choudhary et al., 2011; Oteiza, Giannuzzi, & Zaritzky, 2010). The main principle of UV-C decontamination is based on the formation of photoproducts in the DNA of microorganisms, which prevents their DNA replication (Bintsis, Litopoulou-Tzanetaki, & Robinson, 2000). The UV absorbance spectrum of DNA has a maximum around 260 nm (Koutchma, 2009) being low pressure mercury lamps with peak emission at 254 nm extremely effective to inactivate microorganisms. In liquids, UV absorption and scattering due to solutes and particles are the most important limiting factors which determine the UV-C penetration depth (Koutchma, 2004). This limitation can be compensated by technologies using centrifugal forces to provide thin films (Geveke & Torres, 2013) or by effective mixing to achieve Reynolds numbers in the turbulent range (Franz, Specht, Cho, Graef, & Stahl, 2009; Müller, Stahl, Graef, Franz, & Huch, 2011).

Eggs are worldwide consumed products because of their high nutrient content. It is estimated that in 2015 the Global Eggs Consumption will reach 1154 billion units (Global Industry Analysts, 2011). Liquid egg products are highly susceptible to microbial contamination; however they ought to be pasteurized at mild conditions due to the rheological changes induced by heat. As a result, the shelf life of eggs and egg products, including liquid eggs, is limited to a few days even under refrigeration. Several studies have shown that the organoleptic properties of UV treated liquid egg products are comparable to the untreated, being therefore excellent candidates for UV-C decontamination (Geveke & Torres, 2012; Souza & Fernandez, 2012). Challenges for the UV-C decontamination of egg products are in particular the high optical density of liquid egg fractions, the light scattering due to the Tyndall effect, and the high viscosities. Some microbiological studies have been performed on liquid eggs with successful results (Geveke, 2008; Ngadi, Smith, & Cayouette, 2003; Souza & Fernandez, 2011; Ünlütürk, Atilgan, Baysal, & Tari, 2007; Ünlütürk, Atilgan, Baysal, & Ünlütürk, 2010). The effects of pH, depth of food medium and ultraviolet (UV-C)

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light dose on the inactivation of *Escherichia coli* O157:H7 in egg white were studied by Ngadi et al. (2003). In addition, the efficiency of UV-C irradiation as a non-thermal pasteurization process for liquid egg white was investigated by Ünlütürk et al. (2007, 2010) using a bench collimated beam apparatus, and by Souza and Fernandez (2011) using a bench apparatus with reflector, in both works the target microorganism was *Salmonella enteritidis*. Although, the main challenge in the application of UV-C technology is the scale-up of the process at feasible treatment conditions.

In this study, the microbial efficacy of UV-C treatments in coiled tube reactors up to 20 L h^{-1} has been investigated using inoculated non-pathogenic *Salmonella subterranea*, *Listeria innocua* and *Escherichia coli* strains. The efficacy was evaluated in whole egg, egg white and egg yolk fractions. In addition, the evolution of the natural egg microflora of the UV-C treated liquid egg has been studied and compared with heat treated samples during storage at 4 °C.

2. Material and methods

2.1. Egg samples

Fresh eggs were purchased from Gutshof-Ei GmbH (Schackendorf, Germany). 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 4 °C. Just before the experiments were carried out, the egg content (separately, egg whites and egg yolks) was removed under aseptic conditions, and collected in 1 L sterile flasks. The chalaza was removed and the separated egg fractions were then homogenized for 1 min using a commercial blender (31BL44, Waring, USA) at maximum speed. To prepare the whole egg samples, 13.3 mL of egg yolk was mixed with 26.7 mL of egg white. This proportion is the normal average composition of whole egg and was used to attain a constant white to yolk relationship. Physical parameters of the used egg fractions are shown in Table 1.

2.2. UV-C technology

2.2.1. UV-C chamber for surface treatment

The UV-C chamber constructed by UV-Consulting Peschl® España (Valencia, Spain), already described by Souza and Fernandez (2011) is made of stainless-steel and provided with one low pressure mercury lamp (Heraeus Noblelight GmbH, Hanau, Germany), with maximum peak radiation at 253.7 nm and energy output of 9 W. Chamber dimensions are 50 cm × 50 cm × 60 cm, the inner surface is flat black painted to avoid light reflection at the walls. To enhance the amount of light reaching the samples, an aluminium reflector surface covered the lamp. After UV emission stabilization, the lamp remained on; a shutter between the lamp and the exposition chamber was used to protect the operator without disturbing the operational conditions of the lamp. A magnetic stirrer (Ovan MBG15, Barcelona, Spain) was installed at the central part of the lamp at the level of the sample container.

2.2.2. UVivatec® Lab reactor

For laboratory scale UV-C treatment the UVivatec® Lab reactor (Bayer Technology Services GmbH, Leverkusen, Germany) (Fig. 1a), described among others by Schmidt and Kauling (2007) and Müller et al. (2011) was used. The 9 W UV-C lamp (UVP, Type CPQ-7731) is located inside a quartz glass tube which is wrapped around by a Teflon® helicoid (Fig. 1a) (Poggel, Wübben, Brod, Jenne, & Schmidt, 2008). The lamp used is a low pressure mercury lamp with maximum peak radiation at 254 nm. The liquids can be pumped through the device at flow rates between 2 and 20 L h^{-1} by a peristaltic pump.

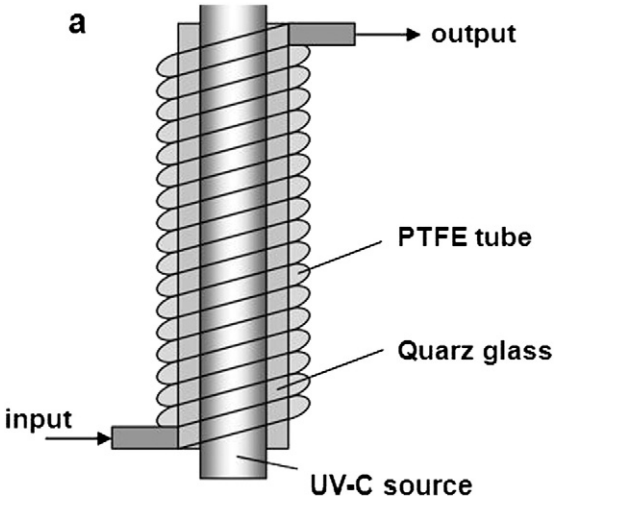

Fig. 1. Principle of the UVivatec® Lab reactor and MRI2010 reactor UV-C modules (with kind permission of Bayer Technology Services).

2.2.3. MRI2010 UV-C reactor

The coiled tube reactor MRI2010 (Fig. 1b) was designed and assembled at the Max Rubner-Institut (Karlsruhe, Germany). The main component is a module which consists of a PTFE envelope with a diameter of 3.7 mm (Adtech Polymer Engineering Ltd., Stroud, UK) which is wound around a 30 W low pressure mercury lamp with maximum peak radiation at 254 nm (UVN 30, UV Technik Speziallampen GmbH, Wümbach, Germany) (Fig. 1b). The liquids can be pumped through the device at flow rates between 4 and 40 L h^{-1} by a peristaltic pump (Pump drive Pd 5206, Heidolph, Schwabach, Germany).

2.2.4. UV-C dosimetry

Several methods are used to compare the efficacy of UV-C treatments. The first method relied on the fluence (D_s in J cm^{-2}) defined as the constant fluence rate multiplied by the exposure time in seconds referring to the available treatment surface (Bolton & Linden, 2003). The UV-C dosage per liter (D_v in J L^{-1}) of treated liquid for a reactor with continuous flow is calculated as the UV-C output of the lamp (W) per flow rate (L s^{-1}) (Keyser, Müller, Cilleirs, Nel, & Gouws, 2008; Wright, Summer, Hackey, Pierson, & Zoecklein, 2000) and used as dose definition in this research project. To compare the inactivation method with others based on relevant energy input (D_{el} in J L^{-1}), the third method relied on the necessary electrical energy input of the lamp (W) per flow rate (L s^{-1}) (Müller et al., 2011).

To specify the flow condition in the reactor at several flow rates Reynolds numbers (Re) were calculated.

$$\mathrm{Re} = \frac{u \times d}{\upsilon} = \frac{u \times d \times \rho}{\eta} \quad (1)$$

where d is the diameter of the tube, u is the velocity (m s^{-1}), υ is the kinematic viscosity (m2 s^{-1}), η is the dynamic viscosity (Pa × s) and ρ is the mass density (kg m^{-3}).

Table 2 gives an overview of the different dose values and Reynolds numbers used in this study.

Table 1
Physical properties of the egg fractions.

	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	10827.89 ± 136.89
Dynamic 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	1.0270 ± 0.0050