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Surface decontamination of whole-shell eggs using far-infrared radiation

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ABSTRACT

Shell eggs from healthy chickens are assumed sterile inside, but numerous microorganisms might be present on the shell. While warm water and controlled microwave applications are some common whole egg pasteurization processes, surface decontamination might be a feasible process since majority of microorganisms are located over the shell. With infrared application's direct influence on the surface, similar to the case of pulsed light and ultra-violet applications, the objective of this study was to determine its potential for surface decontamination of whole-shell eggs. For this purpose, shell eggs were inoculated with *E. coli* ATCC 25922 strain, considering its similar resistance compared to *Salmonella* Enteritidis to heat, and processed under infrared conditions from 180 to 350 °C. Processing at 250 °C for 110 s resulted in 3.37 log cycle reduction without causing any denaturation in albumen and adverse effects in yolk index, Haugh unit, albumen pH and foaming capacity. These results demonstrated the potential of infrared heating for surface decontamination of whole shell eggs as a possible industrial application.

1. Introduction

Eggs are one of the most important economic and balanced protein source available in daily diet, and 540 billion eggs are consumed in the world annually. USDA risk assessment studies indicated the possibility of 1 in 20,000 fresh eggs might contain *Salmonella* Enteritidis (Mermelstein, 2001), and eggs are reported to be most frequently involved with *Salmonella* outbreaks (Hierro et al., 2009; EFSA, 2009; Martelli and Davies, 2012). *Salmonella* is at the top of the CDC list for foodborne illness estimates resulting deaths in the USA (CDC, 2014). It might be inside the eggs (Centers for Disease Control and Prevention, 2005) due to vertical (trans-ovarian transmission in utero to developing pre-ovulatory follicles or trans-shell transmission through shell pores; Hou et al., 1996) or horizontal transmission (contamination of shell after it has formed either during oviposition or from environment following the oviposition; Jones et al., 1995; Choisalkar et al., 2013). While the latter has higher possibility assuming eggs are obtained from healthier chickens, contamination of eggs and eggshells have been identified as one of the major causes of foodborne Salmonella problems (Howard et al., 2012; Whiley and Ross, 2015). Besides the presence of *Salmonella* over the shell, possible shell contamination with other aerobic bacteria and *Enterobacteriaceae* (Jones et al., 2004; Musgrove et al., 2005) is also a possible risk factor. Storage temperature has a certain effect on penetration (Al-Natour et al., 2012) of the microorganisms to the interior of the eggs, and possible contamination of egg contents might also occur via breaking shell for process purposes through the production line.

Various methods have been proposed for egg surface decontamination (FDA, 2009) such as dry cleaning or washing (Hierro et al., 2009; Choisalkar et al., 2013) with alternative approaches for surface pasteurization: ultra-violet irradiation

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(Scott, 1993; Kuo et al., 1997; De Reu et al., 2006), pulsed light treatment (Hierro et al., 2009; Lasagabaster et al., 2011), hot-air application (Manfreda et al., 2010; Pasquali et al., 2010), pulsed ultra-violet light (Keklik et al., 2010) and non-thermal atmospheric gas plasma (Ragni et al., 2010). For surface decontamination purposes, James et al. (2002) determined the applicability of hot-air, hot-water, infra-red radiation and atmospheric steam reporting the requirement of further studies on this subject. Besides surface decontamination approaches, there are also studies in the literature for decontamination of the whole shell eggs. Hot-water based heat treatment (Davidson, 2003), irradiation and ultrasonic treatment (Hou et al., 1996) and controlled microwave (Erasmus and Rossouw, 2012) are possible methods for this purpose. In decontamination of shell eggs, loss of functional properties (foaming, coagulation, emulsification) due to protein denaturation even at low temperatures (e.g., below 60 °C) might be observed (Perry et al., 2011). Therefore, considering the higher possibility of horizontal transmission, surface decontamination without any further damages to the egg constituents would be a preferred way.

Infrared (IR) radiation is one of the oldest ways for processing agricultural products. It is classified into near- (NIR; 0.78 to 1.4 μm), mid- (MIR; 1.4 to 3 μm) and far-infrared (FIR; 3 to 1000 μm) regions. Rastogi (2012) emphasized the efficient heat transfer by IR heating with less process time and energy cost while Sawai et al. (2000) demonstrated that the FIR heating was more effective in eliminating vegetative cells compared to thermal conductive heating. Besides, lower temperature of the emitters in this region, compared to the case of NIR and MIR regions, enables an effective process control. IR processing was applied for surface decontamination of various food products including strawberries (Scheerlinck et al., 2004; Tanaka et al., 2007); turkey frankfurtes (Huang, 2004), hotdogs (Huang and Sites, 2007), fig fruit (Hamanaka et al., 2011), cumin (Erdogdu and Ekiz, 2011), black pepper (Erdogdu and Ekiz, 2013), oregano (Eliasson et al., 2014) and Gorgonzola cheese rinds (Bernini et al., 2015).

Exposing eggs to IR heating results in an increase in shell temperature (due to the shorter wavelength, IR does not have the ability to penetrate deeply), and heat is conducted to interior by conduction. With low thermal conductivity (0.55–0.61 W/m-K; Almonacid et al., 2007; Erdogdu et al., 2007; Fabbri et al., 2012) and high viscosity of albumen (0.0304 Pa-s; Kemps et al., 2010, e.g., ≈30 times higher than water), heat transfer rate (mainly dominated by conduction) inside tends to be rather slow compared to the case of a natural convection heating in a low viscosity liquid product. If the exposure time is then properly controlled, shell temperature can be preferentially raised to a degree that a target microorganism can be inactivated without substantially increasing the interior temperature.

Therefore, the objectives of this study were to evaluate the potential of IR application for surface decontamination of whole shell eggs and compare the possible changes in the quality attributes of the IR processed eggs with the fresh ones.

2. Materials and methods

Through the course of this study, commercial grade 'A' fresh unfertilized table chicken eggs (medium size, 53–63 g) were purchased from a local market and used through inoculation and IR processing experiments. The eggs were stored in refrigerated conditions through the study and kept at room temperature for one night before their use for inoculation and IR processing studies.

Based on the given objectives, this study was carried out in 3-stages. In the first stage, culture preparation and surface inoculation over the egg shells were completed, and this was followed by infrared treatment at various time–temperature combinations. In the last stage, certain physical properties (changes in yolk index, Haugh unit, albumen pH and foaming capacity) of the IR processed eggs were determined to compare the results with the fresh ones.

2.1. Culture preparation and surface inoculation

E. coli ATCC 25922 strain, a useful surrogate for *E. coli* O157:H7, was used to determine the IR effect on the surface decontamination of whole shell eggs for surface penetration studies. Various studies in the literature also demonstrated that the *E. coli* ATCC 25922 strain might be used as a surrogate for *E. coli* O157:H7 (Eblen et al., 2005; Kim and Harrison, 2009). Hence, *E. coli* ATCC 25922 strain was used through the culture preparation and shell inoculation stages.

To prepare the culture preparation for egg shell inoculation, activated *E. coli* ATCC 25922 pure culture strain was grown in a 250 mL TSB (Triptic Soy Broth, Merck) at 37 °C for 18 h to have 10^9 CFU/mL of strain in the culture. This culture was then used in the shell inoculation.

For the inoculation, the eggs were weighed and brushed with soap first. After rinsing out with warm water, they were dipped into 70% ethanol for one minute and washed again with sterile and warm water. These eggs were then located in a sterile laminar air flow cabinet and allowed to dry for 30 min. The shell-dried eggs were then placed in the TSB culture for 10 min under orbital shaking at 200 rpm. Following the inoculation step, the eggs were left to dry for 40 min again in the laminar air flow cabinet prior to the IR processing at various times and temperatures.

2.2. Far infrared processing for surface decontamination

Far infrared processing for surface decontamination was carried out after half an hour following the IR heating unit temperature reached to the process temperature. The infrared heating unit (Fig. 1 demonstrates the schematic representation) was designed with flat electrically operated ceramic emitters, of 650 W with maximum surface temperature of 553 °C (Ceramicx, Cork, Ireland) working under far-infrared conditions. Under the given temperature range, minimum wavelength obtained from the ceramic emitters was 3.507 μm based on the Wien's displacement law (Eq. (1)):

$$\lambda = \frac{2897.6}{(553 + 273.15)} = 3.507\,\mu\text{m} \quad (1)$$

where λ is the wavelength. Considering that the surface temperatures of the heating elements would be lower than the given maximum value, the resulting wavelengths are expected to be higher falling into the far infrared region.

The emitters were installed within aluminum reflectors. Since the infrared heaters radiated in all directions, they were specifically placed within aluminum reflectors to focus as much of the radiation as possible uniformly onto the processed eggs. This unit consisted of 48 ceramic infrared