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Modeling and optimization of the E-beam treatment of chicken steaks and hamburgers, considering food safety, shelf-life, and sensory quality

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ABSTRACT

The present work was carried out to model the effect of E-beam treatment on the safety, shelf-life and sensory attributes of two poultry products, steaks and hamburgers, and to optimize the radiation treatment. The inactivation of *Salmonella* spp. by means of different irradiation doses was modeled using a first order kinetics. The shelf-life was studied by periodically counting the bacterial number in samples. For the modeling of experimental data, only the exponential phase of growth was taken into account. The effect of the irradiation dose on the sensory attributes (appearance, odor and flavor) and instrumental color (L^*, a^* and b^* parameters) was modeled using the Gompertz function and the Activation–Inactivation or linear models. The optimization of the irradiation dose was carried out by maximizing the sensory scores of samples and minimizing the instrumental color changes. The safety and the shelf-life of samples were ensured by introducing constraints into the optimization problem. In the case of hamburgers, the optimum calculated dose was 2.04 kGy, which guarantees the safety of the product and provides the best combination of sensory and instrumental attributes. As regards the steaks, the optimum assessed dose was 1.11 kGy, significantly lower than for hamburgers.

1. Introduction

Nowadays, the sale of food products in individual or domestic portions is very common. In the meat industry, it is possible to differentiate two categories of these presentations: that corresponding with convenience, ready-to-eat (RTE) foods, including different kinds of cooked or dry-cured meats and dry fermented sausages, and small pieces of ready-to-cook (RTC) meat (steaks, hamburgers, etc.). This last category is one of the most common products in the poultry meat industry. To prepare these products, it is necessary to carry out several operations, such as cutting, mixing or shaping, which increase the risk of cross-contamination, the most important contaminant organisms in this case being *Salmonella* spp. and *Campylobacter jejuni* (Nachamkin, 2007; Cutter et al., 2012). In this sense, the main sources of Salmonella contamination, not only in the case of carcasses but also in the case of small pieces, are both the animals themselves during slaughtering

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and the industrial equipment (Lillard, 1990; Domingues et al., 2002; Ruban et al., 2010; Panisello et al., 2000; Cutter et al., 2012). This fact means that, despite the efforts made by the industry, currently it is not possible to avoid the contamination of meat. Consequently, there is a need to improve microbial control so as to minimize the contamination of the final product, in order both to reduce the incidence of foodborne pathogens and to extend the shelf-life of the products.

Heat treatment is the technique most commonly used to reduce the microbial load of many foods. However, this technique cannot be applied to fresh meat due to the associated changes in the product characteristics (flavor, odor, color, appearance or texture). Therefore, to reduce the bacterial number in meat products, including pathogens, different non-thermal sanitizing treatments have been proposed. Of them, high hydrostatic pressure (Lakshmanan and Dalgaard, 2004), oscillating magnetic fields (Barbosa-Cánovas et al., 1998), light pulses (Hierro et al., 2012) or E-beam radiation (Cabeza et al., 2007; García-Márquez et al., 2012) are sound alternatives.

Irradiation is known as an effective way to eliminate foodborne pathogens, such as *Listeria monocytogenes*, *Salmonella* spp., *Yersinia enterocolitica* or *Escherichia coli* O157:H7 (Cabeza et al., 2007, 2009; Schilling et al., 2009). However, it has been reported that this technology has limited application for meat, since an excessive level of irradiation can produce changes in the sensory properties of treated products, which could significantly affect consumer acceptance (Arthur et al., 2005; Lee and Ahn, 2005). In this regard, the odor of excessively irradiated meat has been described as being like rotten egg, cooked meat, hot culture medium, sulfur, alcohol, acetic acid, liver-like serumy, and bloody (Brewer, 2009; Cabeza et al., 2007). Therefore, the adjustment of the irradiation dose is a critical point; it must be set to a level that allows an adequate level of microbial inactivation to be achieved (food safety), while at the same time minimizing the changes in treated meat both to avoid consumer rejection and, an additional, valuable feature, to extend the shelf-life.

The mathematical modeling of the influence of the irradiation dose on both the microbial load reduction and the sensory properties retention of E-beam treated products, permits the quantification of effects and, in a later step, the optimization of treatments (Benedito et al., 2011). For that purpose, it is necessary to consider models that define the inactivation of microorganisms, the change in the sensory properties and the post-treatment growth of spoilage microorganisms in order to estimate the product shelf-life. The model proposed by Bigelow (1921) is probably one of the most commonly used to describe microbial thermal inactivation. This traditional first-order model was developed as a way of quantifying the effect of the duration of the heat treatment on the reduction of the viable organisms. A similar model was used, replacing the time variable by the irradiation dose, to assess the influence of this factor on the inactivation of *L. monocytogenes* in vacuum-packaged cooked ham (Benedito et al., 2011). Other models that have also been used, not only to define microorganism or enzyme inactivation, but also the kinetic changes of quality attributes, are the Gompertz function (Ding et al., 2010) or the Activation–Inactivation model (Soysal, 2008).

The shelf-life of products treated by means of any preservation technology is a very important factor to take into account in order to achieve process optimization; in the case of meat, it is linked to the growth of microorganisms that produce the spoilage of food. In this regard, of the models used to define the microbial growth, Hill's model or the modified Gompertz equation (Huang, 2010) are worth mentioning. However, the classical linear models have also been used because of their simplicity and the acceptable way they fit numerous different cases (Mckellar and Lu, 2004).

Thus, the optimization of the E-beam treatment using the modeling of the radiation effects on the microbial and quality factors of the treated products may be an interesting tool for process design. Although this type of optimization has barely been reported, it has been developed for vacuum-packaged cooked ham (Benedito et al., 2011). However, as far as the authors know, this strategy has not been applied to raw poultry meat. Therefore, the goal of this work was to model the effect of E-beam on the safety, shelf-life and sensory attributes of two chicken products (steaks and hamburgers) and to optimize the radiation treatment, maximizing the product quality while guaranteeing its microbial safety and a reasonable shelf-life.

2. Materials and methods

2.1. Microorganisms

C. jejuni is a very sensitive microorganism to ionizing radiation, with the reported decimal reductions (*D*-value) being less than 0.2 kGy (Clavero et al., 1994; Verde et al., 2004). For this reason, the target organism selected for this study was the other main pathogenic bacteria present in poultry meat, i.e. *Salmonella* spp., namely *Salmonella enterica* serovar Enteritidis (CECT4300) and *Salmonella enterica* serovar Typhimurium (CECT 443). The strains were maintained by freezing (−40 °C) in trypticase soy broth (TSB; Difco), adding 10% glycerol as the cryogenic agent. Fresh cultures were prepared for each experiment by removing a piece of frozen culture from vials and inoculating it into 9 mL of TSB, then incubating it at 32 °C for 24 h. The cultures were then centrifuged (at 4 °C) and the pellet suspended in beakers with 50 mL sterile saline solution, which yielded a bacterial load of approximately 10^8 cells/mL that were used to contaminate meat samples.

2.2. Sample preparation and radiation treatment

Chicken breasts, immediately separated from the carcass, were obtained from a local market and transported to the laboratory at 4 °C. Several breasts were cut into steaks (8–12 g, 3 mm thickness). To establish the death kinetics of Salmonellae, a batch of these steaks was contaminated by immersion for one minute in the bacterial suspension obtained as previously described. The contaminated (kinetics studies) and uncontaminated (for the determination of color, sensory characteristics and shelf-life) samples were packed inside a plastic bag of low gas permeability (diffusion coefficient of 35 cm^3 24 h^{-1} m^{-2} bar to oxygen and 150 cm^3 24 h^{-1} m^{-2} bar to carbon dioxide) and thermo-sealed. Another set of breasts was chopped up (hamburger samples) using a domestic mincing machine and divided into two batches. In order to mimic the deep cross-contamination produced during industrial chopping, a set was contaminated with a bacterial suspension (bs) at the ratio of 1 mL bs/20 g meat prior to being minced. Then, aliquots of 20 g (contaminated and uncontaminated batches) were placed into Petri dishes (0.5 cm diameter and 0.5 cm height). Once the hamburgers were ready, they were handled as described for steaks. The samples were transported (less than 1 h) in insulated polystyrene boxes (<5 °C) to the irradiation plant (IOSNISIOS sterilization S.A., Tarancón, Cuenca,