International Journal of Food Microbiology 233 (2016) 60–72

Contents lists available at ScienceDirect

International Journal of Food Microbiology

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

Multi-criteria framework as an innovative tradeoff approach to determine the shelf-life of high pressure-treated poultry

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ARTICLE INFO

Article history:
Received 17 July 2015
Received in revised form 11 March 2016
Accepted 29 May 2016
Available online 14 June 2016

Keywords:
Risk-risk trade-off
Lactate
Food hygiene
Food safety
Sensorial quality

ABSTRACT

A multi-criteria framework combining safety, hygiene and sensorial quality was developed to investigate the possibility of extending the shelf-life and/or removing lactate by applying High Hydrostatic Pressure (HHP) in a ready-to-cook (RTC) poultry product. For this purpose, *Salmonella* and *Listeria monocytogenes* were considered as safety indicators and *Escherichia coli* as hygienic indicator. Predictive modeling was used to determine the influence of HHP and lactate concentration on microbial growth and survival of these indicators. To that end, probabilistic assessment exposure models developed in a previous study (Lerasle, M., Guillou, S., Simonin, H., Anthoine, V., Chéret, R., Federighi, M., Membré, J.M. 2014. Assessment of *Salmonella* and *L. monocytogenes* level in ready-to-cook poultry meat: Effect of various high pressure treatments and potassium lactate concentrations. International Journal of Food Microbiology 186, 74–83) were used for *L. monocytogenes* and *Salmonella*. Besides, for *E. coli*, an exposure assessment model was built by modeling data from challenge-test experiments. Finally, sensory tests and color measurements were performed to evaluate the effect of HHP on the organoleptic quality of an RTC product. Quantitative rules of decision based on safety, hygienic and organoleptic criteria were set. Hygienic and safety criteria were associated with probability to exceed maximum contamination levels of *L. monocytogenes*, *Salmonella* and *E. coli* at the end of the shelf-life whereas organoleptic criteria corresponded to absence of statistical difference between pressurized and unpressurized products. A tradeoff between safety and hygienic risk, color and taste, was then applied to define process and formulation enabling shelf-life extension. In the resulting operating window, one condition was experimentally assayed on naturally contaminated RTC products to validate the multi-criteria approach. As a conclusion, the framework was validated; it was possible to extend the shelf-life of an RTC poultry product containing 1.8% (*w*/*w*) lactate by one week, despite slight color alteration. This approach could be profitably implemented by food processors as a decision support tool for shelf-life determination.

1. Introduction

Poultry meat is highly perishable as spoilage in raw chicken may occur within a couple of weeks following slaughtering, under refrigerated storage (Lin et al., 2004). Further steps like mincing and mixing, currently used for some processing ready-to-cook (RTC) poultry products even more shorten the shelf-life.

During the entire shelf-life, food products have to be safe and guaranteed for a defined and acceptable quality under expected (or specified) conditions of distribution and storage. Shelf-life determination of RTC products is an important issue for food manufacturers since they have to address the market constraints for longer shelf- life, the need for safety required by regulations and the need for quality required by consumers. For this purpose, they have to comply with legal requirements, *i.e.* i) safety and ii) hygienic criteria (Directive 2000/13/EC and Regulation 2073/2005) but also with iii) organoleptic considerations (FAO/WHO, 2004). They usually do experimental challenge-tests but do not use quantitative tools on a regular basis, except maybe for assessing compliance with safety criteria where predictive microbiology software is available. In the literature dealing with shelf-life extension or determination, there is no quantitative assessment based upon a multi-criteria framework combining the three above criteria. For example, Pereira et al. (2015) evaluated the shelf-life of sliced Portuguese traditional blood sausage without the use of predictive modeling. In the

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http://dx.doi.org/10.1016/j.ijfoodmicro.2016.05.027
0168-1605/

approach followed by Mantilla et al. (2012), the influence of gamma-irradiation on the shelf-life of poultry breast fillets conditioned under modified atmosphere was investigated by successively considering the time-to-reach 7 log cfu/g heterotrophic aerobic mesophilic bacteria and the detrimental effects of the treatment on color and sensory aspects. The only study applying multi-criteria framework to food microbiology, dealt with foodborne risks by considering health, social and market impacts in the objective of prioritization of foodborne risks (Ruzante et al., 2010).

The increasing consumer demand for healthier formulations of meat products, results in a strong tendency of reducing and even removing preservatives and additives in food, such as lactate (Wilcock et al., 2004). High hydrostatic pressure (HHP) represents an innovative alternative approach likely to be used to offset reduction of preservatives. It enables inactivation of foodborne pathogens and spoilage microorganisms while limiting detrimental effects on nutritional and organoleptic qualities of food (Hayman et al., 2004; Patterson, 2005; Simonin et al., 2012).

In a previous study, a HHP treatment step added in an existing process was shown to improve the safety of an RTC poultry product (Lerasle et al., 2014). It enabled the build-up of exposure assessment models associated with *Listeria monocytogenes* and *Salmonella* in an RTC HHP-processed poultry product. The objective of the present study was, with the same product and process, to investigate the possibility of extending the shelf-life and/or removing lactate from the current product formulation by applying HHP. For this purpose, a multi-criteria framework combining safety, hygienic and sensorial quality was developed, taking advantage of the models previously developed for *L. monocytogenes* and *Salmonella* to cover the safety part. Besides, challenge-tests were performed to build the exposure assessment model of *Escherichia coli* in an RTC HHP-processed poultry product associated with the hygienic part. Lastly, the third criterion associated with the organoleptic quality was determined by sensory analysis and color measurements. Combining the three domain-associated results, a tradeoff between quantitative safety, hygienic and sensorial criteria was developed for an extended shelf-life 1) to determine process parameters satisfying all criteria and 2) experimentally test a suitable HHP treatment in order 3) to ultimately validate the multi-criteria framework.

2. Materials and methods

2.1. Overview of the multi-criteria framework

The study was performed with the same product as in the previous study of Lerasle et al. (2014), *i.e.* RTC poultry meat composed with turkey meat (79%), pork fat (11%), spices (<0.1%) and water (10%) provided the day after packaging under modified atmosphere.

A multi-criteria framework combining safety (S), hygienic (H), and organoleptic criteria (O) was used to determine the HHP parameters (pressure intensity and duration) necessary to fulfill the criteria defined below for an extended shelf-life (Fig. 1).

Salmonella and *L. monocytogenes* were selected as safety indicators (Lerasle et al., 2014) whereas *E. coli*, defined as a hygienic indicator by EU recommendation No. 2073/2005, was accordingly chosen as such for assessing the hygienic quality of the poultry product.

The three criteria were quantitative. The two first ones represented a maximum contamination level, at the end of the shelf-life of one or several selected microbial indicators: $N_{upperlimit}$. $N_{upperlimit}$ could be assimilated to a PO (Performance Objective) set in the context of the food safety management framework by ICMSF (2002). The decision making associated to these two criteria consisted in determining the set of combinations of pressure intensity and duration enabling the minimization of these criteria below the set maximum levels, *i.e.* $N_{upperlimit}$, with and without lactate addition (1.8%). $N_{upperlimit}$ was adapted from to microbiological criteria of the foodstuffs defined by the Commission Regulation (EC) No 2073/2005, *i.e.* 100 cfu/g for *L. monocytogenes* in ready-to-eat foods able to support its growth, and 0.04 cfu/g (absence in 25-g) in minced meat and meat preparations made from poultry meat intended to be eaten cooked for *Salmonella*, and 5000 cfu/g in meat preparations for *E. coli*.

The decision was derived from the distributions of the contamination levels. The notion of acceptable risk does not really exist for microbiological risk (Hunter and Fewtrell, 2001). However, in canned products, the rate of spoilage of one spore per 10,000 units is considered as a tolerable level (CCFRA, 1977). Hence in our study, it was considered that the risk of 1/10,000 *i.e.* 0.01% that *E. coli* exceeds 5000 was reasonable whereas a more stringent criterion of 1/100,000, *i.e.* 0.001% was chosen for the risk associated with safety criteria non compliance.

Hence criteria were fulfilled when:

$$P(N_{SL} < N_{upperlimit}) > 99.99\% \text{ for hygienic criteria,}$$

$$P(N_{SL} < N_{upperlimit}) > 99.999\% \text{ for safety criteria}$$

The distributions of the contamination levels of *Salmonella*, *L. monocytogenes* and *E. coli* at the end of the shelf-life, N_{SL}, as a function of HHP and chilled storage conditions (treatment duration and intensity, lactate concentration, storage duration and temperature) were estimated by using exposure assessment models. For *L. monocytogenes* and *Salmonella* exposure assessment models previously built were used (Lerasle et al., 2014). Their modular structure included prevalence data of 100-kg batches stored at 4 °C obtained from factories and influence of mixing, partitioning, HHP and chilled storage steps on RTC product contamination levels.

Regarding *E. coli*, the exposure assessment model had to be built by using new data: first, data from factories to determine the initial contamination level of *E. coli* in RTC products, second, experimental challenge-test data to model the influence of HHP and lactate concentration on the contamination level of *E. coli*, were generated.

Next, by running the probabilistic models, operational HHP process windows enabling respectively to fulfill safety criteria (S) and hygienic criteria (H) were drawn as a function of the shelf-life duration, lactate concentration and HHP conditions.

Besides, color measurements, sensory panel scores and a discrimination test were used to delimit an acceptable operational HHP process window (O). It was defined by HHP conditions that were shown not to produce significant change/damage of the product, which is generally performed in the case of new product development.

A risk-risk tradeoff framework was then conducted to examine the possibility of lactate removal from the current product formulation or at least to enable the extension of the current shelf-life in presence of lactate. Under the selected conditions, all resulting operational windows were superimposed to draw a restricted window for which all criteria were met.

Ultimately, a HHP treatment was then selected inside the resulting operational window for validation of the multi-criteria framework; the experiment was performed on naturally contaminated products.

2.2. High pressure treatment

Two-hundred gram meat samples were high pressure-treated in a 50-L horizontal high pressure pilot unit (ACB pressure system, Nantes, France) under the same conditions as previously described (Lerasle et al., 2014). The samples previously held at 4 °C during storage were inserted into the pressurizing chamber filled with water at 15 ± 1 °C and exposed to HHP. During HHP treatment, the product temperature in the pressure chamber increased because of the adiabatic heating, without however exceeding 10.5 °C.

2.3. Microbiological analyses

For challenge-tests and validation experiments, samples were analyzed one day minimum at 4 °C after HHP, a period of time favoring the repair of injured cells before performing microbiological analyses.