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Influence of vacuum application, acid addition and partial replacement of NaCl by KCl on the mass transfer during salting of beef cuts

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ABSTRACT

The objective of this work was to study the influence of different salting procedures on the water loss (*WL*) and salt gain (*StG*) kinetics of beef cuts. The following procedures were evaluated: wet salting at atmospheric pressure; pulsed-vacuum wet salting (with application of one or three vacuum pulses); dry salting; pulsed-vacuum marination in brines with acetic, citric or lactic acid; and pulsed-vacuum salting in brines with partial replacement of NaCl by KCl. From the obtained experimental results, we verified that the application of three vacuum pulses during wet salting increased the *WL* by 20% and the *StG* by 15% in comparison with the wet salting at atmospheric pressure. In contrast, addition of different acids in the brine decreased the *StG* by 13–24% after 6 h of immersion. Moreover, results obtained with partial replacement of NaCl by KCl revealed that the diffusion of K^+ is faster than of Na^+ and also that KCl has a smaller capability of reducing water activity. This demonstrates the importance of adjusting salting time when using mixtures of NaCl and KCl for elaborating products with reduced Na^+ levels.

1. Introduction

Salting is among the oldest food preservation methods and is one of the major steps for the preparation of dried meat products such as *charque* (a traditional Brazilian dried/salted beef product) and jerked beef (the latter differs from the former mainly by the use of sodium nitrite in the brine during salting). The salting procedures used for preparing these products are the dry salting (DS) and the wet salting (WS). The dry salting is carried out by stacking alternating layers of salt and beef cuts, whereas the wet salting is based on the immersion of the product in brines and involves the transfer of both salt and water between the product and the brine either in the same direction or in counter-current (Schmidt, Carciofi, & Laurindo, 2008b). Besides the salt, other ingredients, such as acids (acetic, citric, lactic and others), can be added to the brine aiming to provide specific sensory characteristics (flavor, softness) and decrease microbial growth and enzymatic activity (Capaccioni, Casales, & Yeannes, 2011; Tribuzi, Schmidt, & Laurindo, 2014). This occurs by the simultaneous action of the salt and organic acids on the muscle proteins, reducing their water-holding capacity and promoting a higher dehydration (Goli, Ricci, Bohuon, Marchesseau, & Collignan, 2014). The influence of the acid addition on the mass transfer (salt and water) kinetics during the marination (salting in brines with acids) has been studied in products as turkey meat (Goli, Bohuon, Ricci, Trystram, & Collignan, 2011), fish (Capaccioni et al., 2011) and cooked mussels (Tribuzi et al., 2014).

The salting of large pieces of meat is usually slow due to the low values of salt diffusivity at the low temperatures required to ensure product safety during processing. In the conventional processing of *charque*, for instance, the salting stage can last up to 8 days (1–2 days for wet salting, followed by 5–6 days of dry salting), followed by a solar drying stage that lasts 5 days or more (Shimokomaki et al., 1998). Aiming to reduce the long salting periods of meat cuts, one interesting alternative may be the use of vacuum impregnation. This technique has been considered in the last decades for both reducing the wet-salting time and promoting a more homogeneous distribution of salt for different types of products, such as cheese (Hofmeister, Souza, & Laurindo, 2005), fish (Corzo, Bracho, & Marjal, 2006), cured ham (Barat, Grau, Ibáñez, & Fito, 2005), turkey and chicken meat (Deumier, Trystram, Collignan, Guédider, & Bohuon, 2003; Schmidt, Carciofi, & Laurindo, 2008a).

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The vacuum impregnation process accelerates salt uptake in porous food due to a combination of hydrodynamic mechanisms (which promote solution uptake due to pressure gradients) with diffusional phenomena promoted by concentration gradients (Chiralt et al., 2001; Fito, 1994).

Another important aspect regarding dried meat products as *charque* and jerked beef is related with their sodium content, since they usually have a NaCl concentration ranging from 15 to 18 g 100 g^{-1} (obtained at the end of the drying stage). Consequently, even considering that these products are partially desalted before meal preparation, their consumption normally results in a high sodium intake that has been associated to chronic diseases such as hypertension, cardiovascular disease, stroke and kidney disease (Albarracín, Sánchez, Grau, & Barat, 2011; Barat, Pérez-Esteve, Aristoy, & Toldrá, 2012). Thus, one notices that the development of strategies for reducing the sodium content of dried meat products is a research topic of great interest for the food industry. Such a reduction can be obtained not only by decreasing the total salt content, but also by the partial replacement of sodium chloride (NaCl) by other chloride salts (KCl, $CaCl_2$, $MgCl_2$) or non-chloride salts (phosphates, among others) (Albarracín et al., 2011). This approach has been applied to cod (Aliño, Fuentes, Fernández-Segovia, & Barat, 2011; Martínez-Alvarez, Borderías, & Gómez-Guillén, 2005), dry-cured ham (Aliño, Grau, Fuentes, & Barat, 2010b; Aliño, Grau, Toldrá, & Barat, 2010a; Armenteros, Aristoy, Barat, & Toldrá, 2012), and dry-cured loin (Aliño et al., 2009). For most of these products, KCl has been the main choice for replacing NaCl mainly due to the physicochemical similarities between these two salts. However, the partial replacement of NaCl by KCl raises a number of questions related to (i) the possible reduction of the salty flavor of the product; (ii) the amount of salt required for ensuring microbiological safety; and (iii) the definition of the required process time considering the differences of the salts with respect to water reduction capacity and mass transfer rates inside the product (Barat, Baigts, Aliño, Fernández, & Pérez-García, 2011). The knowledge of these rates is a key factor for minimizing the variability of both moisture and salt, and also for estimating the time required to achieve a given moisture and salt content in the final product. However, few studies have been carried out aiming to evaluate the salting kinetics of processes involving the partial replacement of NaCl by other salts (Barat et al., 2011; Corzo, Rodríguez, & González, 2012). In this context, the aim of this work was to evaluate the mass transfer kinetics during different salting procedures of beef cuts. To this end, the following procedures were evaluated: (i) wet salting at atmospheric pressure; (ii) pulsed-vacuum wet salting (with application of one or three vacuum pulses); (iii) dry salting; (iv) pulsed-vacuum marination in brines with acetic, citric or lactic acid; and (v) pulsed-vacuum wet salting in brines with partial replacement of NaCl by KCl.

2. Material and methods

2.1. Sample and solution preparation

Cuts of beef chuck produced by a single company were purchased in a local market (in Florianopolis, SC, Brazil). These cuts were used for preparing samples in the form of parallelepipeds with dimensions of 8.0 × 8.0 × 1.5 cm (length × width × thickness) and weight of about 150 g. Only muscles with pH between 5.4 and 5.9 were used. The saline solutions were prepared using distilled water and sodium chloride (purity ≥ 99%, Vetec, Rio de Janeiro, Brazil). The marinades (brines with acids) were prepared using distilled water, sodium chloride, and acetic acid (purity ≥ 99%, Vetec, Rio de Janeiro, Brazil) or citric acid (purity ≥ 99%, Vetec, Rio de Janeiro, Brazil) or lactic acid (purity ≥ 84%, Vetec, Rio de Janeiro, Brazil). The saline solutions with partial replacement of NaCl were prepared using KCl (purity ≥ 99%, Vetec, Rio de Janeiro, Brazil).

The pH of the samples and solutions was measured using a digital potentiometer (Analion, model PH-730, Ribeirão Preto, SP, Brazil).

2.2. Experimental methodology

In the first study, the influence of different salting methods (wet salting at atmospheric pressure, pulsed-vacuum wet salting with application of one or three vacuum pulses, and dry salting) on the mass transfer (water and salt) was evaluated. In the wet salting at atmospheric pressure (APWS), the beef samples were immersed in a saturated NaCl solution (6 mol L^{-1}) at 10 °C for 6 h. A beef to solution ratio of 0.1 g mL^{-1} was used to avoid considerable changes of solution concentration during the salting process. In the pulsed-vacuum wet salting with one vacuum pulse (1VPWS), a pulse with absolute pressure of 6.67 kPa (50 mmHg) were applied to the immersed samples during the first 20 min of the process, followed by 5:40 h of wet salting at atmospheric pressure. The pulsed-vacuum wet salting with three vacuum pulses (3VPWS) involved the application of three successive pulses (of 6.67 kPa for 5 min followed by around 2 min at atmospheric pressure) during the first 20 min of the process, followed by 5:40 h of wet salting at atmospheric pressure. In the dry salting (DS), the beef samples were firstly immersed in a saturated NaCl solution and then completely surrounded with a 5 mm salt layer. Afterwards, the samples were put in a plastic container on a suspended grid (to avoid contact between the samples and liquid exuded during the process) inside a cold chamber at 10 °C for 6 h.

In the second study, the influence on the mass transfer (water and salt) of the addition of acetic acid (AA), citric acid (CA), or lactic acid (LA) to the NaCl solution was evaluated for the pulsed-vacuum marination process (3VPM). The same procedure of the 3VPWS process was used with the difference that the samples were immersed in a saturated NaCl solution having an acid concentration of 0.1 mol L^{-1}.

In the third study, the influence of the partial replacement of NaCl by KCl in the brine was also evaluated for the 3VPWS process. In this context, the conditions studied were: Formulation A – 100% NaCl (≈NaCl 6 mol L^{-1}), Formulation B – 75% NaCl and 25% KCl (≈NaCl 4.5 mol L^{-1} and KCl 1.5 mol L^{-1} solution), and Formulation C – 50% NaCl and 50% KCl (≈NaCl 3 mol L^{-1} and KCl 3 mol L^{-1}).

An overview of the processes considered in this research work is presented in Fig. 1. All the salting processes evaluated were performed in triplicate. For each repetition, in specific process times (20, 40, 60, 120, 180, 240, 300, 360 min), three samples were removed from the container, washed with saturated NaCl solution (to eliminate the possible presence of salt crystals on the surface), drained and gently blotted with filter paper in order to reduce the water adhered to their surfaces. Afterwards, these samples were weighted and separately analyzed as describe in Section 2.4.

2.3. Experimental device

The wet salting procedures (at atmospheric pressure and with vacuum pulses) were performed in an experimental device consisting of a jacketed stainless steel chamber (internal volume of 53.5 L) connected to a stirring pump with a circulating flow rate of 5000 L h^{-1} (Bombinox, model BL 05, São José, SC, Brazil) and also to a vacuum pump with a nominal flow rate of 350 m^3; h^{-1} (DVP, model LC.305, San Pietro In Casale, Italy). The temperature inside the chamber was controlled at 10 °C by circulating cold water in the jacket using a thermostatic bath (Quimis, model Q214M2, Diadema, SP, Brazil). The monitoring of the pressure inside the