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Microstructure and physical changes in the Mexican cooked lamb meat *barbacoa* made with chilled and frozen meat

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ABSTRACT

Longissimus dorci (*LD*) samples of different origin (imported and domestic) with pre-treatments (imported meat stored at −18 °C for 6 months, domestic meat stored at −18 °C for 10 days, and domestic meat stored at 4 °C for 24 h) were cooked as *barbacoa* and frozen using two treatments (air blast and liquid immersion) and then evaluated after 30 days of storage. The results showed that the origin and pre-treatment of meat affected L^*, a^*, instrumental texture and microstructure; that the storage time affected pH, a_w, b^* and microstructure; and that the freezing treatments did not affect the meat. Overall, the frozen cooked lamb dish *barbacoa* could present some problems at the conservation stage due to an increase in pH, a_w and changes in microstructure; however, the physical traits (color and texture) remained mostly unchanged and depended more on the quality of the raw meat.

1. Introduction

Traditional Mexican *barbacoa* is a cooked lamb dish that is produced with national lambs or made with imported frozen carcasses from Australia, New Zealand, and other countries (Rubio, Torres, Gutierrez, & Mendez, 2004). It is typically prepared on the day on which it is sold in markets, street-food stands, restaurants, and festivals in Mexico and even in the United States (Pilcher, 2014). Frozen, precooked *barbacoa* made from beef meat can be found in some supermarkets in the northern region of Mexico. However, no basic information regarding the effect of the freezing process on these types of products has been reported.

Studying the microstructure of foods is key to improving and optimizing food processes (Hernando, Llorca, Puig, & Lluch, 2010) because there is a causal connection between structure and functionality (Aguilera, Stanley, & Baker, 2000). There are diverse contributions that allow us to understand changes in the microstructure of fish and meat during the freezing, thawing, and cooking processes; these typically involve the qualitative analysis of images (Aguilera et al., 2000; Barbut, Gordon, & Smith, 1996; Carroll, Cavanaugh, & Rorer, 1981; Sriket, Benjakul, Visessanguan, & Kijroongrojana, 2007). The use of software to quantitatively analyze images improves the understanding of changes in microstructure; however, there still is no single methodology for analyzing this type of image.

The freezing process can influence meat properties because of the mechanical damage of ice crystal formation in extracellular locations and the volume changes in cellular structures. A slow freezing rate causes more mechanical damage due to the formation of large ice masses and the distortion of muscle tissue structure. However, a fast freezing rate forms more numerous and smaller ice crystals that cause less mechanical damage during the thawing process and reflects more light from meat surfaces (Aberle, Forrest, Gerrard, & Mills, 2012). Previous studies have analyzed ice crystal area formation during the freezing of fish and pork using SEM images (Chevalier, Sequeira-Munoz, Le Bail, Simpson, & Ghoul, 2000; Ngapo, Babare, Reynolds, & Mawson, 1999). For cooked meat, however, most image analyses remain descriptive.

Previous studies have established that frozen ready to eat meat requires the understanding of the interaction of freezing rate, frozen storage time, and storage temperature (Farouk, Wieliczko, & Merts, 2003), which affect meat quality parameters such as: pH, water activity and physical traits (color and texture). Changes on pH rate is a measure of glycolysis, hydrolysis and proteolysis, and it is correlated with meat quality (Aberle et al., 2012; Barbut et al., 1996; Farouk et al., 2003; Jeong et al., 2010). Previous research has observed that pH rate is affected by freeze–thaw cycles (Qi et al., 2012). Water also plays a fundamental role in meat quality as it accounts for 65 to 80% of total muscle mass (Aberle et al., 2012). Water activity (a_w) refers to the unbounded water and it is related to the water available for microorganisms' development (Gill, 2006). Free water is also related to the formation of ice crystals

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that disrupt muscle structures and to the increase of concentration of cell electrolytes that can result in chemical denaturation of muscle proteins and lipid oxidation during freeze–thaw cycles (Creed, 2006; Jaczynski, Hunt, & Park, 2006; Kasapis, 2006).

The color and texture of meat are critical characteristics for consumers (Karpińska-Tymoszczyk, 2014). The rate of postmortem glycolysis which happens during frozen storage is determinant for color development (Jeong et al., 2010). According to Farouk et al. (2003), freezing rate and storage time affect meat lightness. Texture is affected by biological conditions of the animal, methods of slaughter, storage and processing conditions or culinary treatments. During frozen storage muscle may suffer unwanted changes in texture, resulting in a hard and dry product accompanied by myofibrillar proteins aggregation (Sánchez-Alonso, Barroso, & Careche, 2010).

The objective of this study was to evaluate the influence of the origin and pre-treatment of commonly imported and national meat available on the Mexican market, as well as the freezing method and the storage time on the physical, textural, color, and microstructure characteristics of *barbacoa*, the traditional Mexican cooked lamb dish.

2. Materials and methods

Longissimus dorci (*LD*) muscles from six carcass of common Australian imported lamb available on the Mexican market (Merino × Suffolk breed, male lambs, 6–8 months of age, 6 months frozen, grass-fed) were obtained from a national importer in Mexico City and transported in ice boxes within 4 h to the food processing laboratory to be thawed at 4 °C for 24 h before use. The packer reported that after slaughtered carcasses were kept at 4 °C for 24 h and then shipped at −18 °C. Four domestic, cross-bred, entirely male lambs were slaughtered at a local abattoir (Merino × Suffolk breed, 6 months of age, grain-fed). Carcasses were kept at 4 °C for 24 h, kept at −18 °C for 10 days, and finally thawed at 4 °C for 24 h before use. A third group of four domestic lambs from the same flock, once slaughtered, were kept at 4 °C for 24 h before use. The *barbacoa* from every group of carcasses was prepared jointly. The meat was wrapped in maguey leaves and cooked for 6 h in a prototype oven designed to maintain the meat at a temperature of 100.0 ± 2.0 °C.

The design consisted of a comparison between two post-cooking chilling treatments, i.e., conventional air blast (stored directly at −18 °C), and fast chilling with liquid immersion on the *Longissimus dorci* (*LD*) muscles by triplicate per treatment. For the fast chilling treatment (F), samples were put into waterproof, thin-walled polyethylene bags capable of withstanding temperatures as high as 80 °C and were submerged in 2 °C ice water until the meat reached 4 °C. Then they were stored directly at −18 °C. With this method, 4 °C was reached 33 min faster than with the conventional air blast method (C). For both treatments, when the meat reached 20 °C, the samples were removed and were used for time 0 measurements as recommended by equipment manufacturers. When the rest of the meat reached 4 °C, it was individually vacuum-packed using 180 × 370 mm multilayer EVA/PVDC plastic bags with a thickness of 48 to 62 μm. The packed meats from all treatments were kept at −18 °C for 30 days. After this period, the meat was thawed at 4 °C for 24 h before measurements were taken.

2.1. pH and a_w determination

The cook loss (CL) was evaluated as described by Koohmaraie (1996) in six repetitions and was calculated using the formula of Fregonesi et al. (2014). The pH was measured in triplicate using a pH meter (model HI-99163, Hanna Instruments, Brazil) with a combined electrode for the perforation of meat. Water activity (a_w) was measured using an AquaLab Pawkit (Decagon Devices, Inc., United States).

2.2. Instrumental color measurement

The instrumental color, L^*, a^*, and b^* scales of the CIELab system were determined using a portable colorimeter (Minolta Colorimeter CR-300, Minolta Camera Co., Japan) at two different points; six determinations were performed for each cooked sample. A D65 illuminant was used at a standard observation angle of 10° and 8 mm aperture.

2.3. Instrumental texture measurement

Shear force (SF) analysis was conducted on individual parallelepiped (3 × 1 × 1 cm) samples of cooked meat cut parallel to the muscle fibers using a Warner–Bratzler (TA XT-2i Texture Analyzer, StableMicro Systems Ltd., UK), with 3 mm s^{-1} velocity, 30 mm distance, and 5 g strength to determine the shear force. The maximum force required to shear the sample was measured and the results were expressed in Newtons (N). Six determinations were performed for each cooked sample.

2.4. Microstructure

The microstructure of the cooked lamb meat was analyzed by scanning electron microscopy (SEM). Three samples of approximately 0.5 × 0.5 × 0.3 cm were cut transversally to the muscle fibers from the surface (Chevalier et al., 2000). The samples were prepared following the chemical fixation procedure described by Hernando et al. (2010), using a critical point dryer (Tousimis Samdri, 780[a], Japan), a coating (JEOL, Fine Coat Ion Sputter JFC-1100, Japan), and electron microscopy (JEOL operating at 5 kV, JSM-6390, Japan).

Quantitative data were obtained from the images (ImageJ, NIH, United States). The total area of meat viewed in each image was divided into 100 × 100 μ squares. Three squares of each image were randomly selected and passed to a binary image, and in each area, the region of interest (ROI) occupied with black spaces was calculated. The difference between the ROI and the total area was reported as the cooked fiber area of the meat. Images were taken at a 300× magnification with a 50-μm scale bar.

2.5. Statistical analysis

The effects of the origin and pre-treatment of the meat (OPM) (frozen imported meat vs frozen domestic meat vs fresh domestic meat), freezing method (fast vs conventional), and time of storage (0 vs 30 days) on the variables considered in this study were submitted to an analysis of variance according to the following model:

$$Y_{ik} = \mu + O_i + F_j + T_k + O_i \text{ x } F_j + O_i \text{ x } T_k + F_j \text{ x } T_k + O_i \text{ x } F_j \text{ x } T_k + e_{ijkl}$$

where Y_{ik} = values for each variable; μ = least square means; O_i = fixed effect due to the origin and pre-treatment of the meat; F_j = fixed effect due to the freezing method; T_k = fixed effect due to the time of storage; $O_i \times F_j$ = effect due to the interaction between the origin and pre-treatment of the meat and the freezing method; $O_i \times T_k$ = effect due to the interaction between the origin and pre-treatment of the meat and the time of storage; $F_j \times T_k$ = effect due to the interaction between the freezing method and the time of storage; $O_i \times F_j \text{ x } T_k$ = effect due to the interaction between the origin and pre-treatment of the meat, the freezing method and the time of storage; and e_{ijkl} = random residual effect.

All models were fitted using the GLM procedure (SPSS 22.0 for windows, SPSS Inc., USA). To describe the relationships between the variables and the origin and pre-treatment of the meat, a discriminant function analysis (DFA) was performed. Student's *t*-test at a 5% level was utilized to test the differences between freezing methods.

Data from the raw meat were analyzed using analysis of variance with the GLM procedure. Tukey's test was used at the 5% level to make comparisons between the means.