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Prediction of the salt content from water activity analysis in dry-cured ham

Maria Martuscelli [a, *], Laura Lupieri [b], Giampiero Sacchetti [a], Dino Mastrocola [a], Paola Pittia [a]

[a] Faculty of Bioscience and Technology for Food, Agriculture and Environment, University of Teramo, Via R. Balzarini 1, 64100 Teramo, Italy
[b] Wolf Sauris SpA, Sauris di Sotto 88, 33020 Sauris di Sotto, UD, Italy

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ABSTRACT

Salt (NaCl) penetration was studied on dry-cured hams of different weight processed by two different salting processes. Chemical composition and water activity (a_w) were analysed on two of the most representative ham muscles during the process. The normalized Weibull cumulative distribution was used to fit salt uptake in *Biceps femoris* m. (BF) and to calculate the salt diffusion coefficient. The a_w values strictly depend on the Salt Index (S.I., g_{NaCl} 100 g_w^{-1}). The S.I. of BF samples from hams taken at different processing steps, were modelled as a function of a_w by both a linear and a first order polynomial model achieving good fitting ($R^2 = 0.92$). The calibration root mean square error (RMSE) resulted being of 1% for both models. Cross validation was performed and the RMSEs were of 0.62% and 0.61% for the linear and polynomial models, respectively. These models can be useful to manage the salting process in dry-cured hams at industrial level.

1. Introduction

In traditional dry-cured ham the penetration of salt along with other curing agents when used, is determinant for the achievement of physico-chemical properties related to the safety and stability of the final product as well as the development of the characteristic sensory quality. As known, salt influences the growth of microorganisms and bio-enzymatic activities (Toldrá, 2005) that affect the safety and quality (texture, taste, flavour, colour) of the final product (Flores et al., 2012; Serra et al., 2005; Countron-Gambotti et al., 1999).

There are two ways to proceed with salt treatment: undetermined salt or the exact amount of salt supply (Toldrá, 2002); in Mediterranean countries (Spain, Italy, France), during treatment with salt, hams are completely covered with dry salt and placed in refrigerated rooms (0–4 °C, 70–95% R.H.) for a period of time that differs based on product specifications defined by companies (Schivazappa et al., 2010). In addition to the salting procedure (number of steps, length of time between steps), other factors may affect salt uptake including raw material, pH, skin trimming, extra- and intra-cellular fluid, fat layer, intra-muscle fat content, the quality of the salt (type and size distribution) and the room temperature (Arnau and Gou, 2001; Sánchez et al., 2008; Gou et al., 2008; Garcia-Gil et al., 2012).

Diffusion is the most important mass transfer mechanism responsible for salt uptake and water loss, due to the differences in concentration and osmotic pressures among meat cells and salting agent (Raoult-Wack, 1994).

The normalized Weibull distribution is used to measure diffusive phenomena since it's considered an adequate model in order to give an approximate estimation of the diffusivity coefficient (Marabi et al., 2003); this model is also considered as an alternative to Fick's equations for the non suitability of assumptions (Petrova et al., 2015).

From the past decade to the present time many studies were carried out to investigate salt diffusion and loss of moisture during dry-cured ham processing, according to traditional analytical procedures (Grau et al., 2008) or by applying non-destructive alternative methods (Fantazzini et al., 2009; Antequera et al., 2003; Picouet et al., 2013).

Recently, the improvement of salting control is a major goal for meat industry either to avoid oversalting or to meet the increasing demand for low-salt products. Health and nutritional concerns about sodium intake is currently leading food industries to optimise and/or to reduce the salt content in formulated and processed products, also for traditional ones.

* Corresponding author.
E-mail address: mmartuscelli@unite.it (M. Martuscelli).

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Nomenclature

a_w	water activity (−)
B	constant for water activity calculation (−)
β	shape factor of the Weibull equation (−)
β_e	constant for water activity calculation (−)
D_{calc}	calculated diffusivity ($m^2\ s^{-1}$)
D_{eff}	effective diffusivity ($m^2\ s^{-1}$)
l	length (m)
M	molar mass ($g\ mol^{-1}$)
n	dissociation number (−)
R_g	geometric factor (−)
S_0	initial salt concentration ($g_{NaCl}\ 100\ g_{dw}^{-1}$)
S_t	salt concentration at time t ($g_{NaCl}\ 100\ g_{dw}^{-1}$)
S_∞	salt concentration at equilibrium ($g_{NaCl}\ 100\ g_{dw}^{-1}$)
S.I.	salting index ($g_{NaCl}\ 100\ g_w^{-1}$)
$g_{NaCl}\ 100_{ffdw}^{-1}$	salt concentration on fat-free dry weight ($g_{NaCl}\ 100_{ffdw}^{-1}$)
t	time (min)
x	mass fraction ($g\ g^{-1}$)

Different models were developed to predict the salt content by alternative methods to its chemical analysis, that is time consuming and difficult to adapt to quality control routine checks. In particular, some studies tested the applicability of Magnetic Resonance Imaging (MRI) and computed tomography (CT) for the prediction of the salt content in hams (Caballero et al., 2016; Manzocco et al., 2013; Fantazzini et al., 2009; Fulladosa et al., 2010; Santos-Garcés et al., 2010, 2012; Håseth et al., 2012); it has recently been evaluated the feasibility of using non-destructive technologies such as X-rays and ultrasound (US) for predicting the salt uptake in hams during the salting process (Fulladosa et al., 2015a, 2015b).

However, these techniques, useful for research purposes, are not affordable for meat producers as routine analysis tools in order to monitor the process and the final product quality assessment.

The water activity (a_w) in meat products, hightly correlated with salt and moisture contents, is a critical parameter for microbial growth, according to Commission Regulations (EU) No 2073/2005 and No 852/2004 (EU, 2004, 2005); furthermore, a_w value is an important parameter to assure the safety of a long time ripening product as dry-cured ham (Pittia and Paparella, 2016).

In order to evaluate the stability of products in the meat industry, the determination of the a_w is widely used as a tool for quality control, through the use of low cost instruments and with a limited time of analysis (eg. dew point hygrometer or electrical hygrometer), though some authors also evaluated non-destructive method (CT) for predicting a_w in dry-cured hams (Vestergaard et al., 2005; Santos-Garcés et al., 2010).

The aim of this research, carried out on a traditional Sauris PGI dry-cured ham, was: i) to study the salt uptake in different ham muscles with different weights and differently processed in terms of salting procedures; ii) to calculate salt diffusivity in *Biceps femoris* (BF); and iii) to develop mathematical models to predict salt uptake (as defined by salting index, S.I. %) in BF muscles, sampled in different process steps, using water activity (a_w) values measured by dew point hygrometer.

2. Materials and methods

2.1. Materials and dry-cured ham process

A batch of one hundred and ten fresh hams (pH 5.6 ± 0.1) of pigs (crossbreed of Landrace, Large White and Duroc) from the same breeding were selected and used for this study. Upon arrival hams were sorted according to their weight in two classes: fifty five were classified as “small” (S) with an average weight in the range of 13.0–14.0 kg and the other ones were classified as “large” (L) with an average weight in the range of 14.5 ± 15.5 kg. The process was carried out with a partial trimming of hams, such as Prosciutto di Sauris (PGI) specification (EU, 2010).

Five raw hams of each weight batch were used for the analyses of the initial raw material characteristics.

The two weight-batches of raw hams (50 hams each) were then further divided into two process lines different only for the salting procedure (Fig. 1). Keeping constant the length of the salting process: half of each weight-batch (25 hams each) underwent the traditional (3s) salting, that includes 3 steps of dry solid salt coverage procedure, according to the PGI regulation (Martuscelli et al., 2009), and indicated as S-3s and L-3s (according to the respective weight); the other half underwent a modified salting process, that was developed only with 2 salting steps (2s) and indicated as S-2s and L-2s.

The salting process was carried out only with marine salt and no nitrite or nitrate, as described by Martuscelli et al. (2015). An initial complete coverage of the hams with dry salt was initially carried out by a salting machine Saimec RSIX 2582 (Saimec Srl, Parma, Italy); this operation was followed by the manual sprinkling of hams with salt onto specific critical areas (e.g. femur bone). The salt-covered hams were then stored in a salting room at 3 ± 1 °C and 95% RH for 19 days. During this time hams were manually sprinkled twice, at regular time intervals, with tiny amounts of salt to keep them always covered by salt in three total coverage salt steps, (3s-samples). A modified salting procedure was also carried out by performing only one additional salt coating step at the middle of the salting time (e.g. 10 days) (2s-samples).

At the end of salting, each ham of the four batches was cleaned of residual superficial salt by washing and underwent the following process conditions (Martuscelli et al., 2015): (*resting*) 60 days, at increasing temperature from 1 °C to 16–18 °C at a decreasing R.H. up to 85-80%; (*drying* and *smoking)* 15 days, at 20–22 °C, 80–85% RH; (*smearing* and *ripening*) after application on the parts without rind of a mixture of pork fat, cereals flour and pepper *(sugna*), hams have been stored in the ripening rooms under environmental conditions (T: 12–15 °C; RH: 80–85%) for fourteen months since the first salting.

To validate the NaCl predictive models (see Section 2.6) a set of samples of dry cured ham, all collected in local supermarkets, was analysed. In particular this set includes: Sauris PGI hams (n = 16) produced in the same factory as above but coming from different raw materials batches, as well as Parma PDO hams (n = 3), PDO San Daniele hams (n = 3) and *Nostrano Abruzzese* hams (n = 3).

2.2. Sampling

Samples were taken at arrival (green hams, 0 days), at the end of salting (19 days), pre-resting (35 days), resting (97 days), middle ripening (180 days) and end of ripening (420 days). At each sampling time, five hams per weight and salting condition were collected, deboned, and cut on the cross section (10 cm from the bone of the thigh). Two slices (thickness, 3 cm) were taken for sampling at the widest section, according to the procedure described by Grau et al. (2008). Slices were individually packed under vacuum, frozen and stored at −30 °C and analyses were carried out within one week. Before the final sampling and further analysis, slices were left for 2 h at room temperature, sufficient to equilibrate their temperature at 4 °C.

Analyses were carried out on three portions of the cross-section