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Diffusion of sodium chloride in pork tissue

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Abstract

The objectives of the present work were: (a) to establish the effect of brine concentration on porcine tissue microstructure (scanning electron microscopy) and protein denaturation (differential scanning calorimetry), (b) to examine the influence of NaCl concentration on the changes in water content, salt uptake, and protein solubilization, using mass balances, (c) to determine the effect of brine concentration on the diffusion coefficient (D_m) of NaCl in pork tissue (*Longissimus dorsi*) at 4 °C analyzing the influence of water uptake on the results.

DSC thermograms of tissue samples showed three major peaks for untreated tissue corresponding to myosin (57.6 °C), sarcoplasmic protein and collagen (66.2 °C) and actin (80.3 °C). When the tissue was treated with increasing NaCl concentrations the number of peaks was reduced and maximum temperatures of the peaks changed. For D_m determination a transient radial diffusion system was adopted using cylinders of *Longissimus dorsi* that were immersed in brines of different concentrations. Theoretical curves of the diffusional model were fitted to experimental NaCl uptake values corrected by the tissue water content. The increase of D_m with NaCl concentration was attributed to the fact that salt penetration affects cellular structure. Results were interpreted by micrographs, protein denaturation and changes in the tissue water holding capacity.

Keywords: Diffusion coefficient; Sodium chloride; Meat curing; Water holding capacity; DSC

1. Introduction

Sodium chloride has been traditionally used in curing processes. Sodium chloride acts as preservative and modifies water holding capacity of the proteins. One of the functions of NaCl in meat products is to extract myofibrillar proteins. Extraction and solubilization of these muscle proteins contributes to meat particle binding, fat emulsification, and water-holding capacity, and thus, it reduces cook losses and improves quality and texture (Sofos, 1986).

Meat processing requires a thorough understanding of the mechanisms causing the changes in water retention and protein solubility that accompany the treatment with NaCl. Such understanding requires a detailed knowledge of the structural changes that occur, including the changes in water content and protein solubilization (Offer & Knight, 1988a).

In meat research, water-holding capacity (WHC) is a ubiquitous term used to describe the ability of meat to retain its natural water content, closely related to WHC is the ability of meat to take up additional water at elevated salt concentrations (Offer & Trinick, 1983). WHC is studied extensively because of its enormous economic importance. The WHC influences the sensory properties of the product such as juiciness, texture, and flavor (Trout, 1988). It is generally accepted that only myosin and actin, and to some extent tropomyosin, are responsible for the water-holding capacity of meat (Morrisey, Mulvihill, & O'Neill, 1987).

When meat cuts are immersed in curing salts, salt penetration is related to the equilibrium between the salt

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concentration in the interior of the meat piece and the external brine solution. Diffusion of salt in meats has been studied by many workers (Djelveh & Gros, 1988; Dussap & Gros, 1980; Fox, 1980; Gros, Dussap, & González-Méndez, 1984; Sabadini, Carvalho, Sobral, & Hubinger, 1998; Wang, Tang, & Correia, 2000; Wood, 1966). For the controlled manufacture of these products, it is important to know the factors influencing salt penetration and to be able to predict the diffusion rate.

Differential scanning calorimetry (DSC) is a powerful technique for studying the thermodynamics of protein stability and it can provide basic understanding of meat protein denaturation (Barbut & Findlay, 1991; Stabursvik, Fretheim, & Froystein, 1983; Thorarinsdottir, Arason, Geirsdottir, Bogason, & Kristbergsson, 2002). The three major transitions observed in a typical beef muscle homogenate have been attributed to muscle proteins as follows: 54–58 °C, myosin; 65–67 °C, myosin, sarcoplasmic proteins and collagen; 71–83 °C actin, as actomyosin and as fragments of F and G actin monomers (Findlay, Stanley, & Gullett, 1986; Stabursvik & Martens, 1980; Wright & Winding, 1984). Increasing the NaCl content of a muscle homogenate has been shown to destabilize the thermal stability of myosin and actin (Kijowski & Mast, 1988; Quinn, Raymond, & Harwalkar, 1980).

The objectives of the present work were: (a) to establish the effect of brine concentration on porcine tissue microstructure and protein denaturation; (b) to examine the influence of NaCl concentration on the changes in water content, salt uptake, and protein solubilization using mass balances; (c) to determine the effect of brine concentration on the diffusion coefficient of sodium chloride in pork tissue (*Longissimus dorsi*) at 4 °C analyzing the influence of the water uptake on the results.

2. Materials and methods

Longisimuss dorsi pork tissue, free of visible fat, was used in all the experiments.

2.1. DSC studies

DSC studies were performed in a Polymer Laboratories (Rheometric Scientific Equipment, UK). Small meat pieces (approximately 500 mg) were immersed in NaCl solutions of 5, 10, 20, 30, 40, and 50 g/l for 3 h. Samples of 9–10 mg were obtained from the center of each of the small pieces. The samples were placed in aluminum pans and hermetically sealed. A good contact between the sample and the bottom of the pan was assured. The heating rate of the scans was 10 °C/min within a range of 20–110 °C using as reference an empty double pan. After DSC analysis, the pans were punctured and the dry weight of the samples was determined after drying under vacuum at 95 °C until constant weight. Peak temperatures were obtained from the DSC thermograms. Each assay was done using at least four samples.

2.2. Electron microscopy

Small pieces of tissue of 0.5 cm in diameter and 0.2–0.3 cm thick were used for electron microscopy analysis. The samples were immersed in different NaCl concentrations during at least 48 h until equilibrium concentrations were attained The samples were fixed during 24 h according to Pinotti, Graiver, Califano, and Zaritzky (2001) and dehydrated using a series of gradually increasing concentrations of ethyl alcohol. Samples were mounted on aluminum stubs using a double-sided tape and then coated with a layer of gold (40–50 nm), allowing surface and cross-section visualization. Micrographs of the samples were obtained with a scanning electron microscope (JEOL, JSMP 100, Japan).

2.3. Mass balances

Small pork meat cylinders (2 cm length × 1.5 cm diameter) were weighted to obtain the initial weight of each sample (M_0) and afterwards they were immersed in NaCl solutions of different concentrations (10, 30, 70, 100, 140, 200, 330 g/l). The solutions were vigorously stirred (IKA Labortechnik) to assure constant solute concentration at the solid–fluid interface. Immersion times used were 15, 30, 60, 90, 120, 150, and 180 min; after immersion, samples were weighed again (M_1), and dried under vacuum at 95 °C (AOAC, 1984) until constant weight (M_2).

To measure the amount of NaCl present in the tissue (m_{NaCl}) after each immersion period, dried meat tissue was homogenized in an Omnimixer equipment (Sorvall Omni-Mixer 17106, Du Pont Instrument, Newtown, Conn., USA) with bidistilled water at 90 °C. The suspension was stirred, diluted with water and filtered. NaCl was determined by measuring chloride on a 100 ml aliquot with an ion-selective electrode (Cole-Parmer 27502-12) previously calibrated. Experiments were performed in duplicates at 4 °C in a thermostatic chamber. Dry-matter content of untreated tissue samples was also determined ($m_{\text{dry tissue }0}$).

Equilibrium concentrations of NaCl and water were obtained by immersing tissue samples (2 cm length × 1.5 cm diameter) in the different brines during at least 48 h.

Mass balances were proposed in order to analyze changes in the water, proteins, and NaCl content in the tissue.

2.4. Water holding capacity

The effect of NaCl on WHC at long contact times was calculated as the variation between the water content after immersion the sample in the NaCl solution (m_{water}) and the initial water content ($m_{\text{water }0}$) referred to this last value

$$\text{WHC} = \frac{m_{\text{water}} - m_{\text{water }0}}{m_{\text{water }0}} \quad (1)$$

2.5. Effective diffusion coefficients of NaCl in the tissue

To determine the diffusion coefficients of NaCl in the tissue, a radial (unidirectional) diffusion system was adopted using long cylinders of *Longissimus dorsi* pork tissue (10 cm length and approximately 1.5 cm diameter) that were immersed in brines of sodium chloride. The solutions were stirred to get constant solute concentration at the solid–fluid interface. At different times, two cylinders were taken out from the brine and the end zones of the cylinders were discarded to avoid end effects; only the central zone of each cylinder (2.5 cm length) was analyzed. The content of NaCl in the samples was determined at different contact times (15, 30, 60, 90, 120, 150 min). Experiments were performed at 4 °C in thermostatic chambers. Once the samples were removed from the brine, the content of chloride ion was measured using a selective electrode (Cole-Parmer 27502-12). The tissue was homogenized with distilled water at 90 °C and the suspension was processed as previously described in Section 2.3.

Experiments were performed in duplicates; the initial water content of the tissue was measured in duplicates in each test.

Mass transport of a solute from the surface towards the center of a solid food is normally analyzed as a pseudo-binary system (solute-tissue). However due to the complex nature of food tissues, the strongly heterogeneous structure, and the water behavior, exact analytical solutions for binary systems cannot always be applied (Zaritzky & Califano, 1999). Different authors have determined effective diffusion coefficients in meat tissues (Djelveh & Gros, 1988; Dussap & Gros, 1980; Fox, 1980; Gros et al., 1984; Sabadini et al., 1998; Wang et al., 2000; Wood, 1966), however different results were reported.

For an infinite cylinder, the diffusion mechanism in porous materials can be expressed in terms of an effective matrix diffusivity (D_m). It can be considered that the solute is diffusing in the solid matrix through the aqueous liquid phase, then:

$$\frac{\partial C}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(rD_m\frac{\partial C}{\partial r}\right) \tag{2}$$

where C is the solute concentration in the liquid phase of the foodstuff; r, the radius of the cylinder; D_m, the effective diffusion coefficient in the tissue (m^2/s), and t, time (s). The solution of Eq. (2) depends on the boundary conditions. When the solid material, initially containing C_0 concentration of the solute (expressed as mass of solute per mass of water in the tissue), is brought suddenly (at $r = R$) into contact with a well-stirred solution of constant solute concentration C_f at the interface, the boundary conditions are as follows:

$$\begin{aligned} &t = 0, \quad C = C_0, \quad 0 \leqslant r \leqslant R \\ &t > 0, \quad C = C_f, \quad r = R \\ &t > 0, \quad \frac{\partial C}{\partial r} = 0, \quad r = 0 \end{aligned} \tag{3}$$

Considering these boundary conditions the analytical solution of Eq. (2) is (Crank, 1957):

$$\frac{C - C_f}{C_0 - C_f} = 1 - \frac{2}{R}\sum_{n=1}^{\infty}\frac{\exp(-D_m\alpha_n^2 t)J_0(r\alpha_n)}{\alpha_n J_1(R\alpha_n)} \tag{4}$$

where $(R\alpha_n)$ are the n-roots of equation $J_0(R\alpha_n) = 0$ being J_0 the zero-order and J_1 the first-order Bessel's functions.

The total solute uptake at a given time t, $M(t)$ was calculated by integrating Eq. (4) between 0 and R.

$$M(t) = M(\infty)\left(1 - \sum_{n=1}^{\infty} 4\frac{\exp(-D_m\alpha_n^2 t)}{R^2\alpha_n^2}\right) \tag{5}$$

where $M(t)$ is the mass of solute that enters in the tissue during time t; $M(\infty)$ is the maximum amount of solute that could enter at infinite time and corresponds to the concentration of salt in the tissue that is in equilibrium with the external solution. Both, $M(t)$ and $M(\infty)$, were expressed as g solute/g water in the tissue. The dimensionless total uptake $M^* = M(t)/M(\infty)$ was then calculated. A computer program was used to determine the diffusion coefficients of NaCl. Values of D_m were proposed and predicted values of M^* were obtained using Eq. (5). In this equation, the diameter of each sample at the end of the experiment was considered. The value of diffusivity that led to a minimum sum of the residues and of the square residues was selected by an iterative procedure. Residue was considered as the difference between the experimental and the calculated M^* values.

2.6. Statistical analysis

Statistical analyses were done using (SYSTAT Inc., 1990, version 5.0). Significant differences between means were determined by the least significant difference ($P < 0.05$).

3. Results and discussion

3.1. DSC analysis

DSC thermograms of porcine tissue were analyzed to establish the effect of NaCl on protein denaturation (Fig. 1). Untreated tissue samples showed three peaks, with T_{max} values of 57.6 °C, 66.2 °C, and 80.3 °C. The three peaks observed corresponded to myosin (I), sarcoplasmic proteins and collagen (II), and actin (III). Similar results were reported by Quinn et al. (1980) who found T_{max} at 59, 66.5, and 81 °C for myofibrillar pork tissue. Martens and Vold (1976) and Wright, Leach, and Wilding (1977) reported that in bovine *M. semimembranosus* the high temperature peak ($T_{max} = 80$ °C) is due to actin denaturation, while the two peaks with T_{max} values 59 and 66 °C are representing the denaturation of myosin.

After soaking the samples in brine solutions of 5 and 10 g NaCl/l these three peaks were still observed, although they were lost definition (Fig. 1). T_I increased to 59.2 °C

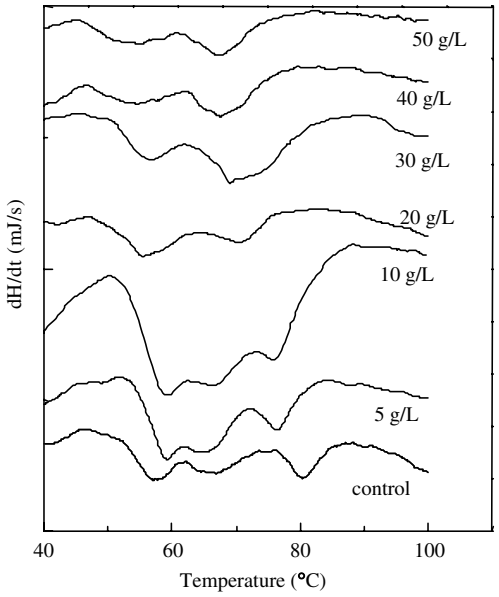

Fig. 1. Thermograms of *Longissimus dorsi* pork muscle after different treatments with increasing concentrations of NaCl.

and T_{III} decreased to 77.4 °C ($P < 0.05$) with respect to the control samples. Quinn et al. (1980) reported that with the addition of 13 g/l of NaCl the T_{max} values of the three peaks observed were 57.5, 71, and 74.5 °C.

When NaCl concentration in the brine was increased to 20, 30, 40, and 50 g/l only two peaks were observed in the thermograms (Fig. 1). The maximum temperature of the first peak decreased from 56.5 to 53.0 °C and the second one from 70.3 to 67.7 °C in the assayed concentration range. Thus, peaks II and III were contracted to one peak that according to the literature corresponds mainly to actin thermal transition.

Kijowski and Mast (1988) working with water-washed myofibrils, reported that when the level of NaCl increased up to 40 g/l, the first peak (myosin) and the second (actin) decreased. They observed that T_{max} decreased from 58.4 to 53.6 °C in the case of myosin and from 80.7 to 64.0 °C for actin. Thorarinsdottir et al. (2002) found that the salt-curing of cod muscle using 147 g/l NaCl decreased, made broader, and less separable the transitions peaks compare to the fresh tissue. They reported that after brine salting the peaks shifted to lower temperatures and it was not possible to distinguish between the respective transitions of sarcoplasmic proteins and myosin. This was likely due to an expected decrease in sarcoplasmic proteins and partial breakdown of the myosin during brining, indicating disassociation of the myosin heavy chain. Besides they reported that the peak corresponding to actin transition shifted from 73.5 to 67.0 °C.

3.2. SEM micrographs

SEM micrographs of meat tissue treated with different solutions showed microstructural changes; micrographs of samples treated with NaCl 5, 140 and 330 g/l for 48 h contact times are observed in Fig. 2. The sample treated with NaCl 5 g/l (Fig. 2a) shows slight differences with respect to the untreated sample (not shown), the essential structure of the myofibrils appeared to be intact. Fibers in Fig. 2b submitted to NaCl 140 g/l show swelling, while NaCl 330 g/l (Fig. 2c) produced fragmented and dehydrated fibers, with a granular appearance.

3.3. Mass balances in meat tissue during brine immersion

Mass balances were needed to quantify water and salt uptake, and protein solubilization during brine immersion.

Initially muscle tissue was considered formed by water and dry matter (the initial content of NaCl was negligible) thus the following equation was proposed:

$$M_0 = m_{\text{dry tissue }0} + m_{\text{water }0} \tag{6}$$

where M_0 is the initial mass of the sample, $m_{\text{dry tissue }0}$ is the initial dry tissue content, and $m_{\text{water }0}$ the initial water content in the tissue.

After immersion in NaCl solution, the salt was incorporated to the sample and some soluble substances were leached to the solution, then:

$$M_1 = m_{\text{NaCl}} + m_{\text{dry tissue}} + m_{\text{water}} \tag{7}$$

where M_1 is the mass of the sample, m_{NaCl} is the mass of NaCl that was uptaken by the tissue, $m_{\text{dry tissue}}$ is the mass of dry tissue, and m_{water} the water content of the tissue; all these magnitudes were evaluated after immersion of the sample in the brine.

The solids content after immersion (M_2) was considered as the sum of NaCl and dry tissue contents, then the mass of dry tissue after immersion was evaluated as

$$m_{\text{dry tissue}} = M_2 - m_{\text{NaCl}} \tag{8}$$

During immersion in the brine solutions part of the protein was solubilized; this amount was calculated by the following equation:

$$m_{\text{solubilized tissue}} = m_{\text{dry tissue }0} - m_{\text{dry tissue}} \tag{9}$$

Average water content in the untreated tissue ranged between 72% and 74%.

Fig. 3 shows the experimental values of WHC (Eq. (1)) as a function of NaCl concentration in the brine at long contact times that is, under equilibrium conditions. Meat tissue treated with increasing concentrations of NaCl showed important modifications. For NaCl concentrations in the solution ranging between 5 and 200 g/l the tissue gained water. The maximum water uptake was observed for NaCl concentrations ranging between 70 and 100 g/l. Above 200 g/l the water holding capacity decreased showing water loss at 330 g/l.

Similar results were reported by Knight and Parsons (1988) working with rabbit muscle; they found that there was net uptake of water below 4.5 M (260 g/l) NaCl with a maximum at 1 M (58.5 g/l), but loss of water is produced above 260 g/l.

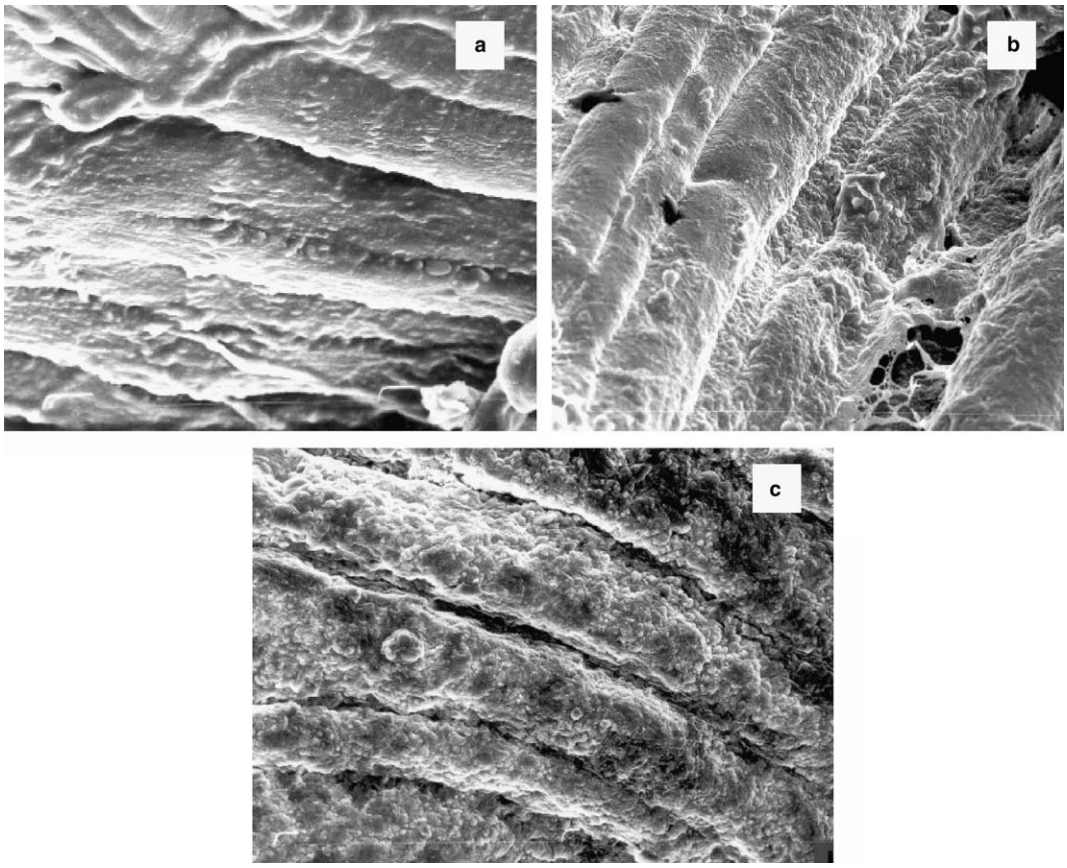

Fig. 2. SEM micrographs of pork tissue treated with different solutions of NaCl 5, 140 and 330 g/l: (a) samples treated with NaCl 5 g/l, (b) samples treated with NaCl 140 g/l, (c) samples treated with NaCl 330 g/l. Scale: 100 mm between marks.

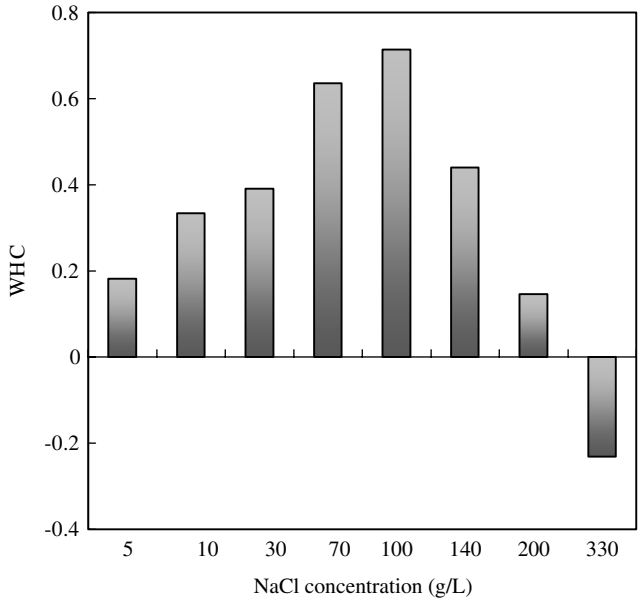

Fig. 3. Water holding capacity WHC = $((m_{water} - m_{water\,0})/m_{water\,0})$ as a function of the brine concentration at long contact times (equilibrium conditions).

At low NaCl concentrations, swelling of the fibers, and high values of water holding capacity were observed in the present work in agreement with the results reported by Offer and Trinick (1983) and Belitz and Grosch (1997). The increase in water holding capacity might be attributed to the lateral expansion of myofibrils, which is coupled to protein solubilization. According to Xiong, Lou, Harmon, Wang, and Moody (2000), an increase in water binding and hydration in salted meat and muscle fibers are generally attributed to enhanced electrostatic repulsion between myofibril filaments causing the filament lattices to expand for water entrapment. Akse, Gundersen, Lauritzen, Ofstad, and Solberg (1993) reported that salting-in and swelling of the muscle occurs at lower salt concentration (<50 g/l), but salting-out of proteins is observed at higher concentrations (above 90–100 g/l) that implies a strong bond between water and salt and the subsequent protein dehydration.

Using the experimental values and the mass balances different mass ratios were determined such as: m_{NaCl}/M_0, m_{water}/M_0, $m_{solubilized\ tissue}/m_{dry\ tissue\,0}$.

Fig. 4a and b shows that the ratio m_{water}/M_0 increased as a function of time; however when NaCl concentrations in the brine were lower than 100 g/l, water uptake increased with salt concentration (Fig. 4a), while for higher NaCl concentrations (140 and 200 g/l) the opposite was observed (Fig. 4b). Table 1 shows this ratio for all the assayed concentrations reaching equilibrium values for long contact times (48 h).

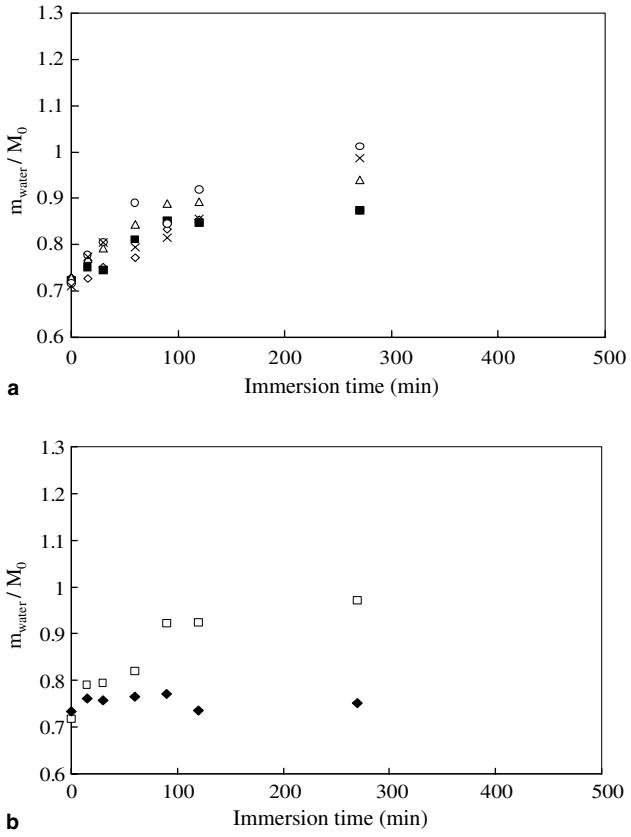

Fig. 4. Mass of water/initial mass of tissue (M_0) as a function of time for different brine concentrations (a) ◇: 5, ■: 10, △: 30, ○: 70, ×: 100 gNaCl/l and (b) □: 140, ◆: 200 gNaCl/l.

Table 1
Mass of water/initial mass of tissue (M_0) and mass of NaCl/initial mass of tissue (M_0) for different brine concentrations at long immersion times

NaCl concentration (g/l)	M_{water}/M_0	M_{NaCl}/M_0
5	0.862	0.004
10	0.974	0.006
30	1.037	0.021
70	1.196	0.082
100	1.251	0.090
140	1.051	0.225
200	0.843	0.164

Fig. 5 shows the ratio between the mass of NaCl uptaken by the tissue and the initial mass of the sample (m_{NaCl}/M_0) for different immersion times and NaCl concentrations. This ratio increased as a function of time for all the assayed concentrations reaching equilibrium values for long contact times (48 h) (Table 1).

The ratio between the amount of solubilized protein (Eq. (9)) and the initial dry tissue content increased during immersion time. The highest value was observed for 70 g/l NaCl in the solution for long contact times (Fig. 6a). Fig. 6b shows the effect of immersion time on the amount of solubilized protein for NaCl concentrations of 30 and 70 g/l. Significant differences ($P < 0.05$) in the amount of

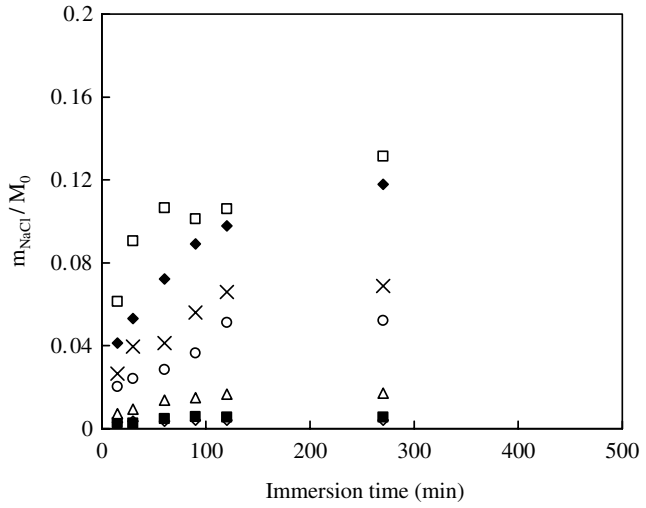

Fig. 5. Mass of NaCl/initial mass of tissue (M_0) as a function of time for different brine concentrations: ◇: 5, ■: 10, △: 30, ○: 70, ×: 100, ◆: 140, □: 200 gNaCl/l.

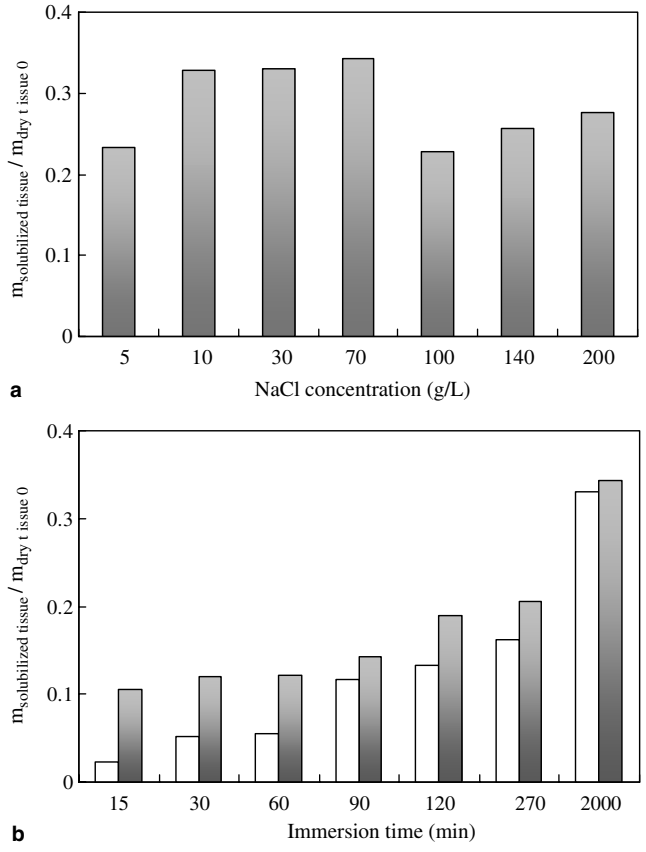

Fig. 6. Ratio between the amount of solubilized protein and the initial dry tissue content: (a) as a function of NaCl concentration for long contact times, (b) as a function of immersion time for NaCl concentrations of □ 30 and ■ 70 g/l.

solubilized proteins were observed. At 70 g/l protein solubilization was faster than at 30 g/l reaching similar values at long contact times. Knight and Parsons (1988) working

with rabbit muscle obtained similar results; they reported that extraction of protein followed the same pattern as water, showing a peak at around 58.5 g/l NaCl and a decline at higher NaCl concentrations (263 g/l).

3.4. Diffusion coefficients of sodium chloride in meat tissues

Meat tissue cannot be considered as formed by an insoluble matrix and an aqueous phase through which the solute diffuses, since part of the proteins are solubilized; besides water penetrates into the matrix.

In order to determine the diffusion coefficients, NaCl uptakes $M(t)$ and $M(\infty)$ expressed as g solute/g water in the tissue (Eq. (5)) were corrected by the water content of the sample at each time and the dimensionless total uptake $M^* = M(t)/M(\infty)$ was then calculated.

Fig. 7 shows as an example, the experimental and predicted values of M^* as a function of contact time, for NaCl concentration of 70 g/l. A satisfactory agreement between experimental and predicted values was observed. The average relative error along the curve was less than 9%.

The obtained values of the diffusion coefficients of NaCl in pork tissue at 4 °C are shown in Table 2 for the assayed brine concentrations. As can be observed the diffusion coefficient increased with the NaCl concentration.

In agreement with this results Wang et al. (2000) reported equations that predicted salt diffusivities in the Atlantic salmon muscle as a function of brine concentration; for post-rigor fish the proposed equation was $D_m = (1.08 + 0.59C') \times 10^{-10}$ m^2/s, where C' was the NaCl concentration in g/g salt free solid, obtaining values of D_m ranged from 1.09 to 1.52×10^{-10} m^2/s for thawed samples immersed in NaCl concentration of 200 g/l at 10 °C.

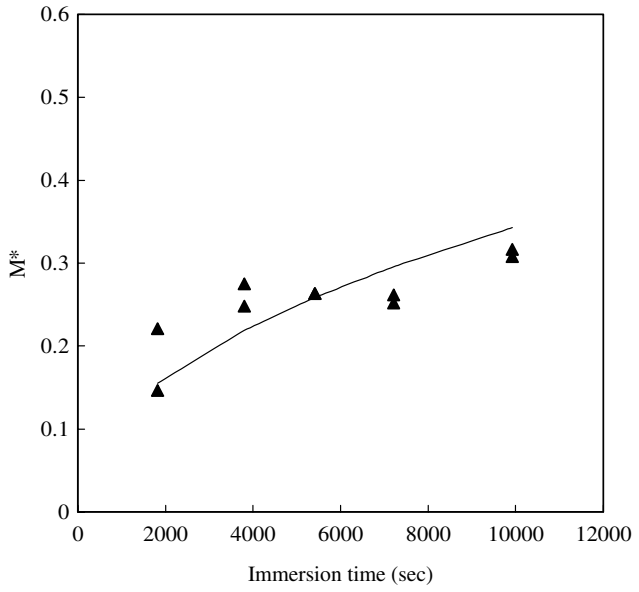

Fig. 7. M^* as a function of contact time for 70 g/l brine concentration: ▲ experimental values, — predicted curve.

Table 2
Effective diffusion coefficient of NaCl (D_m) in pork tissue

NaCl concentration (g/l)	$D_m \times 10^{10}$ (m^2/s)
30	0.60
70	1.10
100	1.70
140	1.85
200	5.00

Djelveh and Gros (1988) reported higher diffusion coefficients than those obtained in the present work, because they worked with beef muscle frozen and thawed with a diffusion cell at 25 °C. Using NaCl concentrations ranged from 100 g/l to 200 g/l obtained diffusion coefficients that increased from 7.17×10^{-10} m^2/s to 8.73×10^{-10} m^2/s, respectively. They explain these increase because swelling may have occurred during solute transfer at the muscle-solution boundary in the high salt concentration tank.

The increase of the diffusion coefficient with salt concentration can be attributed to the effect of NaCl on the fibers microstructure as was described in the SEM section; NaCl disrupts the fiber tissues and facilitates its penetration at higher concentrations (Pinotti et al., 2001).

Other authors reported values of diffusion coefficients of salt in meat tissues. The diffusion coefficient obtained by Fox (1980) in *Longissimus dorsi* pork tissue for NaCl 180 g/l in the brine using a diffusion cell ($D_m = 2.2 \times 10^{-10}$ m^2/s at 5 °C) agrees with the result obtained in the present work. Wood (1966) found in *Longissimus dorsi* pork immersed in saturated salt solution (320 g/l) D_m coefficient of 2.2×10^{-10} m^2/s at 12 °C. Sabadini et al. (1998) obtained a value of 2.5×10^{-10} m^2/s for the diffusion coefficient of NaCl in beef in a saturated solution at 10 °C and Rodger, Hastings, Cryne, and Bailey (1984) reported a value of 2.3×10^{-10} m^2/s at 20 °C using fish fillets in a NaCl saturated solution. Dussap and Gros (1980) worked with samples of meat stood on a bed of salt at 2 °C; the model for the salt penetration considered the meat porosity that represents the percentage of dry matter. They obtained a diffusion coefficient value of 2.2×10^{-10} m^2/s at 2 °C. Gros et al. (1984) found at 2 °C in pork *Longissimus dorsi* a value of $D_m = 2.19 \times 10^{-10}$ m^2/s.

In contrast, high values of the diffusion coefficients are reported in literature by Sabadini et al. (1998) that obtained a value of the diffusion coefficient of NaCl of 19.37×10^{-10} m^2/s dry salted beef at 20 °C. Del Valle and Nickerlson (1967) reported values of diffusion coefficients ranging between 11.8 and 14.5×10^{-10} m^2/s at 25 °C in fresh Swordfish muscle immersed in NaCl concentrations ranged from 5.8 to 180 g/l. These values extremely high are close to the diffusion coefficients of NaCl in pure water ($D = 8.16 \times 10^{-10}$ m^2/s at 4 °C and 14.8×10^{-10} m^2/s at 25 °C).

High values are expected for example in agar gels but not in meat tissues having a solid matrix structure. In the present work, when experimental data were not affected by the actual amount of water present in the tissue, we also

overestimated the diffusion coefficients obtaining values close to the diffusivities of NaCl in water.

Therefore, when uptake experiments are used to obtain NaCl diffusion coefficients different factors such as: water flux, solute concentration expressed per volume of liquid in the tissue and protein solubility have to be considered to get accurate results.

4. Conclusions

The structural characteristics of cured pork tissue are affected by chemical and physical changes in the muscle fiber. Important modifications were observed by scanning electron microscopy (SEM) when the tissue was treated with increasing concentrations of NaCl. Besides, the number of peaks observed in DSC thermograms were reduced and maximum temperatures shifted to lower values due to protein denaturation.

Mass balances allowed to determine in the tissue samples the changes in water content, salt uptake, and protein solubilization. At low concentrations of NaCl swelling of the fibers, and high values of the water holding capacity were observed. At higher NaCl concentrations the phenomenon was reversed, fiber volume decreased, the tissue lost its own water and proteins precipitated causing disruption in the matrix.

The effect of brine concentration on sodium chloride diffusion coefficient was analyzed; the increase of D_m with NaCl concentration was attributed to salt penetration that affects cellular structure. The importance of considering the actual water content in the tissue on the D_m values was also discussed.

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