World Rabbit Sci. 2017, 25: 377-385
doi:10.4995/wrs.2017.6687

MASS TRANSFER DYNAMICS DURING BRINING OF RABBIT MEAT

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Abstract: As a traditional processing method, brining is a preliminary, critical and even essential process for many traditional rabbit meat products in China. The aim of this work was to investigate mass transfer of rabbit meat brined in different salt concentration. Rabbit meat (*Longissimus dorsi*) was brined for 24 h in 5 brine solutions (5, 10, 15, 20 and 25% NaCl [w/w]). Results indicated that mass transfer and kinetics parameters were significantly affected by the brine concentration during brining. When brine concentration increased, the total and water weight changes decreased, whereas the sodium chloride weight changes increased. Higher brine concentrations resulted in a higher degree of protein denaturation and consequently gave lower process yields. Samples treated with higher brine concentrations obtained lower brining kinetic parameter values for total weight changes and water weight changes, whereas they acquired higher values for sodium chloride weight changes.

Key Words: rabbit meat, brining, mass transfer.

INTRODUCTION

In the last 20 yr, total rabbit meat production worldwide has risen 1.7 fold, reaching 1.78 million tons in 2013. Europe, Asia, Americas and Africa are currently the main rabbit meat producing areas, accounting for some 37.1, 38.7, 18.8 and 5.4% of the total production, respectively (FAO). Nowadays, rabbit meat is increasingly suitable for contemporary consumers because of its low cholesterol contents, high digestibility, high levels of essential amino acids and polyunsaturated fatty acids, and a high degree of vitamin B family (B2, B3, B5, B6, and B12) contents, compared with other meats (Dalle Zotte *et al.,* 2011). There is a long history of eating rabbit meat in China. Rabbit meat products, such as Chansi-cured rabbit, water-boiled salted rabbit and cold-eating rabbit, are traditional and popular meat products in China. The saying –no rabbit, no feast– could reflect the important role of rabbit meat in the traditional eating habits of local residents.

As an old processing method, brining is used to prepare meat either for immediate consumption or as a preliminary step in preservation (Petracci *et al.,* 2013). The brining is achieved by using salt in the form of aqueous solution and is believed to cause a series of variations which are responsible for the changes in flavour, colour, texture and nutritional value. In the brining process, there are gradient differences among meat inter cells and brine solution (Zhang *et al.,* 2011). The gradient differences would exist in the whole process until the absolute end of the brining is reached. Due to the gradient differences, treated meat samples can gain solutes from the salt solution. Thus, mass transfer occurs during the brining, which mainly includes the penetration of salt and diffusion of water (Sabadini *et al.,* 1998). Research on mass transfer dynamics can provide a better understanding of the transport phenomena during brining.

Nowadays, mass transfer in many foodstuffs, such as pork, turkey, duck and fish, has been widely studied by many researchers (Gallart-Jornet *et al.,* 2007; Schmidt *et al.,* 2008; Graiver *et al.,* 2009; Aliño *et al.,* 2010; Du *et al.,* 2010; Goli *et al.,* 2011; Filipović *et al.,* 2012; Leng *et al.,* 2013). Many factors such as brining time, salt concentration and

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https://doi.org/10.4995/wrs.2017.6687

brining temperature could affect mass transfer. Raw material is one of the major factors affecting mass transfer in meat during brining. The mass transfer of rabbit meat during brining is different from that in other meats due to the influence of the fat content, rigour state and other intrinsic factors in the muscle. Thus, in this study, rabbit meat was selected as the research object to investigate mass transfer. The aim of our study was to examine the influence of different salt concentrations (5, 10, 15, 20 and 25% [w/w]) on the mass transfer of rabbit meat during brining for up to 24 h.

MATERIALS AND METHODS

Materials

Two hundred and forty frozen *Longissimus dorsi* (LD) from HYLA rabbits were provided by College of Animal Science and Technology of Southwest University (China). The meat samples were first vacuum-packed and then deep-frozen with an ultra-low temperature freezer (Haier, China), followed by storing at –18°C for less than 60 d until use. Commercial food grade salt was purchased from Jingxin Salt (Chongqin, China) to make five brine solutions (5, 10, 15, 20 and 25% NaCl [w/w]).

Sample preparation

Frozen meat samples were thawed at 4°C for 20 h before use. Thawed meat samples were first cut into units (2×1×1 cm) and then individually weighed by electronic analytical balance (BSA323S, Sartorius, Germany) and tagged. Brining processing was performed in plastic tanks with plastic wraps covering on the surface for 5 brine concentrations at a ratio of 1:3 (rabbit meat: salt solution). All the above operations were carried out at 4°C.

Three samples were randomly taken from five concentration brines at pre-set times (0, 1, 2, 3, 5, 7, 9, 12 and 24 h) to be analysed. They were weighed after drainage using absorbent paper and immediately homogenised using a high speed disperser (XHF-D, Ningbo Xingzhi Biotechnology Co., Ltd., Zhejiang, China). The homogenised samples were used to measure moisture and sodium chloride content.

Measurement of sodium chloride and moisture content

The salt content of rabbit meat and brines was determined by the $AgNO_3$ solution titration method. Water content of rabbit meat was measured by drying the fresh and salted rabbit meat samples to constant weight in an oven (DHG-9240A, Shanghai Qi Xin Scientific Instrument Co., Ltd. China) at 104±1°C (Deumier *et al.,* 2003).

Measurement of myofibril proteins structure

The myofibril proteins were isolated and purified following the method described by Xiong *et al.* (2000) and Cao *et al.* (2015), with some modifications as described later. Ten grams of sample were first homogenised using a high speed disperser in 40 mL of ice-cold extract phosphate buffer at pH 7.0 containing 100 mM NaCl, 2 mM $MgCl_2$ and 1 mM EDTA-2Na and then centrifuged (9500 g/15 min/4°C) using Avanti J-30I centrifuge (Kurt Backman, USA. After repeating the previous extraction process 3 times, the sediment was washed with 40 mL of wash phosphate buffer at pH 6.25 containing 100 mM NaCl and 10 mM NaN_3, followed by centrifugation (9550 g/15 min/4°C). The washing process was also done in triplicate. The purified myofibril proteins were stored for less than 48 h at 4°C until use. Myofibril proteins concentrations were measured using the biuret method (Robinson *et al.,* 1940).

Myofibril proteins surface hydrophobicity was investigated by the hydrophobic chromophore bromophenol blue (BPB) method according to Sante-Lhoutellier *et al.* (2007), with slight modifications, as described later. Myofibril proteins were diluted to 5 mg/mL with 20 mM phosphate buffer at pH 7.0. One millilitre of myofibril proteins in suspension and 200 µL of 1 mg/mL bromophenol blue were fully mixed. Mixed liquor, 1 mL of 20 mM phosphate buffer at pH 7.0 and 200 µL of 1 mg/mL bromophenol blue, was used as the control. The resulting samples were simultaneously shaken for 10 min at room temperature and then centrifuged at 4000 *g* for 10 min. The supernatants were diluted in a ratio of 1 to 10 using phosphate buffer at pH 7.0. The phosphate buffer at pH 7.0 was used as a blank and the absorbance was read at 595 nm. The amount of BPB bound was calculated by equation (1).

$$BPB(\mu g) = \frac{200\mu g \times (OD_{control} - OD_{sample})}{OD_{control}} \quad (1)$$

Intrinsic fluorescence was evaluated by scanning diluted myofibril proteins with an F-2500 fluorescence spectrophotometer (Shimadzu, Japan) according to Qiu *et al.* (2014), with slight modifications. Briefly, myofibril proteins were diluted to 0.5 mg/mL with 6 mM NaCl solution and scanned between 300 and 400 nm. The excitation wavelength was set at 295 nm and the data were collected at 1500 nm/min. The solution of 6 mM NaCl was used as blank for all samples. All the above operations were done in triplicate.

Statistical analysis

Statistical analysis was carried out by SPSS 19.0. One-way Analysis of Variance was used to analyse the differences between the brines. A simple linear regression was used to analyse the kinetic parameters. Significance of difference in all statistical analyses was set at $P<0.05$.

RESULTS AND DISCUSSION

In the raw rabbit meat, water (x_0^w, %) and sodium chloride (x_0^{NaCl}, %) contents were 75.96±0.60 and 0.117±0.021, respectively.

According to Andrés *et al.* (2002) and Barat *et al.* (2004), a good model for meat brining operation could predict not only the total, water and salt weight changes of the meat, but also the meat liquid phase composition and concentration changes. Hence, such a model must be composed of mass balances, an appropriate definition of the system equilibrium and kinetics equations. In the present study, the equations mentioned below were associated with these aspects in modelling the brining process. In addition, the application of these equations in the experimental data would be explained.

Mass balances of rabbit meat in different salt solutions (5, 10, 15, 20 and 25% NaCl [w/w]) in the process of brining

In general, the components transferred between rabbit meat muscle and salt solutions during brining mainly included water, sodium chloride and some protein and fat exudates. However, these exudates can be ignored due to their small amount (Gallart-Jornet *et al.,* 2007; Du *et al.,* 2010; Leng *et al.,* 2013). Thus, regarding the mass balances in meat, the sum of moisture and sodium chloride weight changes (ΔM_t^w and ΔM_t^{NaCl}) at different brining times should be nearly equal to the total weight changes (ΔM_t^o) (equation [2]). In this study, ΔM_t^o ΔM_t^w and ΔM_t^{NaCl} were calculated by the following equations (3-5), (M_0^o and M_t^o were the total rabbit meat weight at brining time 0 and t. x_0^{NaCl}, x_t^{NaCl} and x_0^w, x_t^w were the sodium chloride contents and the water contents in the meat samples at brining time 0 and t, respectively) (Du *et al.,* 2010; Leng *et al.,* 2013).

$$\Delta M_t^o = \Delta M_t^w + \Delta M_t^{NaCl} \quad (2)$$

$$\Delta M_t^o = \frac{M_t^o - M_0^o}{M_0^o} \times 100(\%) \quad (3)$$

$$\Delta M_t^w = \frac{M_t^o \cdot x_t^w - M_0^o \cdot x_0^w}{M_0^o} \times 100(\%) \quad (4)$$

$$\Delta M_t^{NaCl} = \frac{M_t^o \cdot x_0^{NaCl} - M_0^o \cdot x_0^{NaCl}}{M_0^o} \times 100(\%) \quad (5)$$

As shown in Figure 1, the total weight changes of the rabbit meat were significantly affected by the brine concentration during processing. As brine concentration increased, the total rabbit meat weight gain gradually decreased. Samples treated with the lower brine concentrations gave the higher process yields. This could be explained by the different magnitude of the driving forces in the brining system (Gallart-Jornet *et al.,* 2007) and by the different degree of protein denaturation (Barat *et al.,* 2002). Moreover, the muscle could swell when sampled with lower NaCl concentrations. Knight *et al.* (1988) found myofibrils of rabbit meat swelled most in 1M (5.8%) NaCl, and a maximum net uptake of water was also observed in the same solution. This concentration was close to the concentration of 5% NaCl (w/w)

that caused the highest weight uptake in the present study. These results were similar to the observations made by other researchers (Gallart-Jornet *et al.,* 2007; Du *et al.,* 2010).

Changes in water and sodium chloride weight of rabbit meat in five salt solutions during brining are shown in Figure 2. From these results, water and sodium chloride weight changes were significantly affected by the brine concentration during brining. The sodium chloride weight changes increased with increasing brine concentration. Contrariwise, the water weight changes decreased as the brine concentration increased. Samples treated with the solution of 5, 10 and 15% NaCl (w/w) brines gained moisture in the process of brining. However, in the 20 and 25% NaCl (w/w) brine solutions, rabbit meat lost moisture throughout the brining, and the most concentrated brines resulted in the highest water loss of rabbit meat. Lower brine concentration obtained higher moisture uptake, probably due to the effects of salting-in on proteins (Van *et al.,* 2010). However, when samples were treated at a higher salt concentration, salting-out process resulted in less space for water, and consequently caused the decrease in water content (Van *et al.,* 2010). These results agreed with the observations made by Van *et al.* (2010) and Du *et al.* (2010).

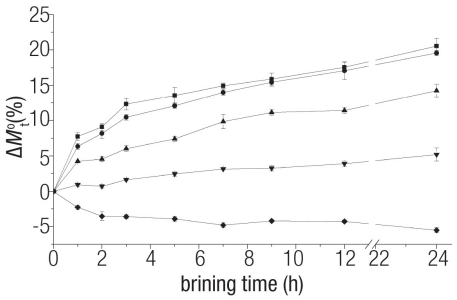
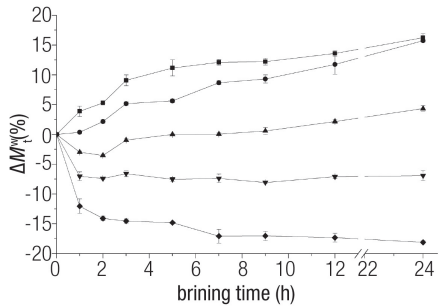


Figure 1: Alterations in overall weight of rabbit meat (ΔM_t^o) in the 5 brines (■: 5%, ●: 10%, ▲: 15%, ▼: 20% and ◆: 25% NaCl [w/w]) during brining.



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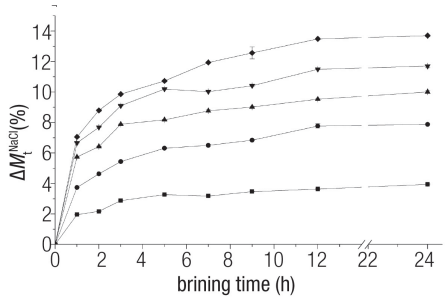

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Figure 2: Alterations in water (ΔM_t^w) and sodium chloride (ΔM_t^{NaCl}) of rabbit meat in the 5 brines (■: 5%, ●: 10%, ▲: 15%, ▼: 20% and ◆: 25% NaCl [w/w]) during brining.

Modification of myofibril proteins structure of rabbit meat in different salt solutions (5, 10, 15, 20 and 25% NaCl [w/w])

Figure 3 presents changes in the surface hydrophobicity (BBP bound) of myofibril proteins from rabbit meat treated in five brines for 24 h. From these results, the BBP bound gradually increased with increasing brine concentration, indicating that surface hydrophobicity of myofibril gradually increased when the brine concentration increased. Because of the property for testing alterations in physical and chemical states of proteins, BBP bound is considered a good indicator of protein denaturation (Sante-Lhoutellier *et al.,* 2007). Generally, the increase in surface hydrophobicity was likely associated with the exposure of hidden hydrophobic residues in the proteins (Qiu *et al.,* 2014). In turn, the exposure of hydrophobic groups could facilitate the denaturation of proteins (Thorarinsdottir *et al.,* 2002). Higher surface hydrophobicity implied higher degree of proteins denaturation (Nakai *et al.,* 1986). Figure 4 presented intrinsic fluorescence spectra of myofibril proteins from rabbit meat treated in 5 brines for 24 h. From these results, a broad band with a maximum at 335 nm was obtained in the control sample, and red shifts were observed in all brined samples, indicating the exposure of hidden hydrophobic residues to the polar or aqueous environment, especially the indole side chain of tryptophan (Lefevre *et al.,* 2007). The changes in surface

hydrophobicity and fluorescence intensity demonstrated that the brining process resulted in denaturation of proteins, and higher salt concentration brines led to higher degree of protein denaturation.

Equilibrium Equations

According to Barat *et al.* (2004), the equilibrium of the brining system could be defined from 2 aspects. One is no further changes in weight, and the other is no further changes in salt concentration in the meat muscle tissue liquid phase (z^{NaCl}).

In terms of the first aspect, Equation 3 was used to describe the equilibrium of the system. As shown in Figure 1, at the late stage of brining, the total weight increase of all samples remained almost constant, as depicted by a plateau in the curve, indicating this stage was close to the brining equilibrium.

Regarding the second aspect, changes in z^{NaCl} throughout the brining and salt concentration in the meat muscle tissue liquid phase at equilibrium (z_e^{NaCl}) were studied as follows. According to Barat *et al.* (2002), z^{NaCl} was calculated by following equation, (x^w and x^{NaCl} were the weight fractions of moisture and sodium chloride in the rabbit meat muscle, respectively).

$$Z^{NaCl} = \frac{x^{NaCl}}{x^w + x^{NaCl}} \times 100\% \quad (6)$$

Changes in z^{NaCl} values throughout the brining in five brine concentrations were shown in Figure 5. From these results, z^{NaCl} values gradually increased with increasing brine concentration. At the initial stage of the brining, z^{NaCl} values increased very quickly, as indicated by a distinctly sharp curve. Thereafter, z^{NaCl} values approached their maximum and remained almost constant after 12 h of sampling, visualised as a plateau in the curve. Different salt gain in meat observed between different brines was probably due to the nature and magnitude of the driving forces (Aliño *et al.,* 2010). At the initial stage of brining, the driving forces resulted from the concentration gradient between brine and muscle were maximum and very high (Aliño *et al.,* 2010), and hence a fast increase rate in z^{NaCl} values was observed. However, as the brining time elapsed, this gradient probably decreased because a high salt concentration layer present on the meat surface served as a barrier to prevent further salt uptake (Telis *et al.,* 2011). These results were similar to the observations made by Aliño *et al.* (2010).

Normally, as the brining reached its equilibrium, the salt concentration in the meat muscle tissue liquid phase at equilibrium (z_e^{NaCl}) was equal to that in the salting solution

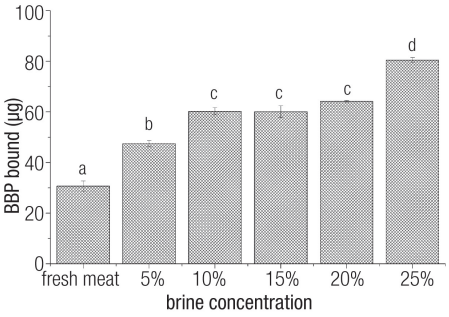

Figure 3: Changes in surface hydrophobicity (BBP bound) of myofibril proteins of rabbit meat after treatment in different brines for 24 h.

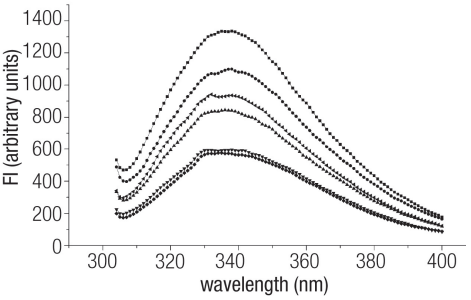

Figure 4: Fluorescence intensity (FI) spectra of myofibril proteins of rabbit meat after treatment in different brines for 24 h. ▪: fresh meat, ●: 5%, ▲: 10%, ▼: 15%, ◆: 20%, ◀: 25%.

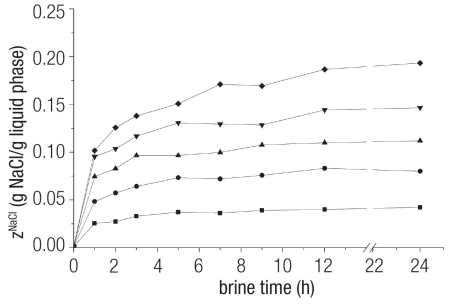

Figure 5: z^{NaCl} values of rabbit meat in the 5 brines (▪: 5%, ●: 10%, ▲: 15%, ▼: 20% and ◆: 25% NaCl [w/w]) during wet salting.

(y_e^{NaCl}) (Gallart-Jornet *et al.,* 2007; Du *et al.,* 2010; Leng *et al.,* 2013). The theoretical equilibrium values (z_e^{NaCl} and y_e^{NaCl}) can be calculated if the initial salted rabbit meat muscle (SR), salting solution (SS) ratio (M_0^{SR}/M_0^{SS}) and initial composition of salt and water were established by a mass balance, (x_0^w and x_0^{NaCl} were water and salt weight fraction in the rabbit meat muscle, respectively. y_0^w and y_0^{NaCl} were water and salt weight fraction in the salting solution), as shown in the Equation 7 (Barat *et al.,* 2004).

$$z_e^{NaCl} = y_e^{NaCl} = \frac{\frac{M_0^{SR}}{M_0^{SS}} \cdot x_0^{NaCl} + y_0^{NaCl}}{\frac{M_0^{SR}}{M_0^{SS}} \cdot (x_0^w + x_0^{NaCl}) + (y_0^w + y_0^{NaCl})} \times 100\% \quad (7)$$

The theoretical z_e^{NaCl} values of rabbit meat calculated by the above equation in 5 brines were 0.040, 0.080, 0.120, 0.160 and 0.200 respectively, and the experimental z^{NaCl} values at 24 h of brining were 0.044, 0.085, 0.112, 0.148 and 0.195 respectively. The result showed that the samples treated with the solution of 5% and 10% NaCl (w/w) brines for 24 h had reached salt equilibrium. Regarding the solution of 15, 20 and 25% NaCl (w/w) brines, the experimental z^{NaCl} values were close to the theoretical z_e^{NaCl} values, indicating that the samples brined for 24 h were close to salt equilibrium and they would reach salt equilibrium if treatment continued for several hours.

Meat liquid phase composition changes

According to Andrés *et al.* (2002), the changes in meat liquid phase composition throughout the brining were caused by several mass transfer mechanisms. In fact, these mechanisms can be simplified as those affected by pressure gradients, namely hydrodynamic mechanisms (HDM), and those dependent on activity gradients, namely the pseudo-diffusion mechanisms (PDM). The latter was usually modelled by the Fick's equations.

In the present study, an integrated solution of Fick's equation for a semi-infinite slab (Equation 8) (Gallart *et al.,* 2007), which takes the effect of the HDM into account, was used, (z_0^{NaCl}, z_t^{NaCl}, and z_e^{NaCl} were the sodium chloride concentrations in the lipid-phase of rabbit meat muscle at brining time 0, t and equilibrium, respectively; y_t^{NaCl} was the sodium chloride concentration in the brine solution at brining time t; l_i was the total thickness of rabbit meat(≅1cm); D_e ($m^2 \cdot s^{-1}$) was the effective diffusion coefficient; Y_t^{NaCl} was the decreased dynamic between the liquid phase of rabbit meat muscle and the sodium chloride brine; the independent term K was used to adjust the deviation from the origin of co-ordinate).

$$1 - Y_t^{NaCl} = 1 - \left(\frac{z_t^{NaCl} - y_t^{NaCl}}{z_0^{NaCl} - z_e^{NaCl}}\right) = 2 \cdot \left(\frac{D_e \cdot t}{\pi \cdot l_i^2}\right)^{0.5} + K \quad (8)$$

The parameters (D_e and K) are presented in Table 1. From these results, similar D_e values were observed in the solution of 5, 10 15 and 20% NaCl (w/w) brines, whereas a higher D_e value was observed in the solution of 25% NaCl (w/w) brines. D_e value was associated with the effective diffusion rate of salt. Higher D_e value indicated quicker meat lipid phase concentration. Higher D_e value in the saturated brines could be explained by a boundary layer with higher salt concentration existing on the meat surface and by the higher driving force resulting from the higher salt concentration (Du *et al.,* 2010). In addition, a higher degree of protein denaturation in saturated brines resulted in muscle shrinkage, which consequently affected the salt diffusion (Van *et al.,* 2010). These results were similar to the observations made by Du *et al.* (2010). As to K value, higher K values were observed at the lower brine concentrations. Generally, K value can describe the initial stage of brining. Higher K value indicated a higher increase rate in z^{NaCl} at the initial stage of brining. Higher K values at the lower brine concentrations could be explained by the fast initial salt and water gain in the hydrodynamic mechanism (Du *et al.* 2010). These results were in agreement with the observations made by Du *et al.* (2010). In addition, high values of R^2 calculated from Equation 8, were obtained

Table 1: The kinetic parameters (D_e, effective difusion coefficient; K value, correction coefficient).

Brine concentration (%)	D_e (m^2/s)	K	R^2
5	1.77×10^{-10}	0.6703	0.8510
10	2.19×10^{-10}	0.6083	0.8111
15	1.55×10^{-10}	0.6195	0.7613
20	1.96×10^{-10}	0.5483	0.8153
25	4.24×10^{-10}	0.4251	0.8853

in 5 brine concentration levels, indicating a strong linear relationship for all brine concentration levels.

Mass transfer dynamics of rabbit brining

In order to obtain the kinetic constants for the mass transfer and present a detailed explanation on the development of process yield, a pseudo-diffusional transportation would be assumed and the weight changes were thought to be in relation with the square root of time (Gallart-Jornet *et al.,* 2007; Du *et al.,* 2010; Leng *et al.,* 2013). The following equation (Gallart-Jornet *et al.,* 2007) was applied to the data in the present study. Figure 6 presented the total weight changes (ΔM_t^o) as the function of the square root ($t^{0.5}$) of sampling time, and kinetics parameters (k_1 and k_2) were presented in Table 2.

$$\Delta M_t^i = 1 + k_1 + k_2 \times t^{0.5} \quad (9)$$

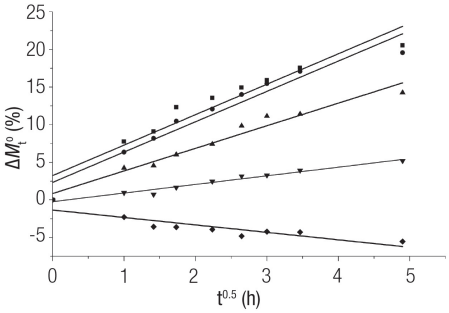

Figure 6: Plot of sample overall weight changes (ΔM_t^o) *vs.* the square root of time $t^{0.5}$ (h). ■: 5%, ●: 10%, ▲: 15%, ▼: 20% and ◆: 25%.

In terms of the total weight changes (ΔM_t^o), the slope term (k_2) was associated with the kinetics of diffusion mechanisms, and hence it was related to process yield (Andrés *et al.,* 2002). As shown in Table 2, k_2 values gradually decreased when the brine concentration increased. In general, differences in k_2 values indicated that salt concentration affected diffusion mass transfer kinetics, and hence the total weight changes were unequal. Regarding the k_1 values, the same tendency as for k_2 values was observed. Generally, the independent term (k_1) could describe what happened at the very initial stage of the brining process, and it was influenced by pressure gradients and hydrodynamic mechanisms. These observations in k_1 and k_2 values for ΔM_t^o were similar to the results of other reports (Barat *et al.,* 2002; Gallart-Jornet *et al.,* 2007; Du *et al.,* 2010).

In terms of the moisture weight changes (ΔM_t^w) and sodium chloride weight changes (ΔM_t^{NaCl}), k_2 values were considered to relate to the effective diffusion rate of water and sodium chloride (Andrés *et al.,* 2002), and k_1 values can describe what happened at the very early stage of the brining process. When brine concentration increased, k_1 and k_2 values for ΔM_t^w gradually decreased (Table 2). The k_1 value for ΔM_t^w of samples treated with the solution of 5% NaCl (w/w) brines was positive, whereas those of the other groups were negative. As to the solution of 5% NaCl (w/w) brines, the positive k_1 values for ΔM_t^w indicated that pressure gradients were a stronger force compared to water activity gradients, because of the swelling of the myofibrils induced by sodium chloride in the early stages of the brining process (Van *et al.,* 2010). On the contrary, k_1 and k_2 values for ΔM_t^{NaCl} gradually increased with increasing brine concentration, indicating that mass transfer of sodium chloride was driven by a concentration gradient between the muscle and brine (Van *et al.,* 2010). Higher k_2 values for ΔM_t^{NaCl} in more concentrated brines may be explained by a greater magnitude of the driving forces (Van *et al.,* 2010). Moreover, larger extracellular spaces resulted from salting-out and shrinkage of the muscle fibres in more concentrated brines also contributed to higher effective diffusion rates of sodium chloride (Van *et al.,* 2010). In addition, high values of

Table 2: Dynamics parameters (k_1 and k_2) and the fitting correlation factors for total (ΔM_t^o), water (ΔM_t^w) and NaCl weight changes (ΔM_t^{NaCl}).

	Brine concentration (%)	k_1	k_2	R^2
ΔM_t^o	5	2.2419	4.0481	0.9187
	10	1.3347	4.0321	0.9434
	15	–0.1447	3.004	0.9639
	20	–1.2251	1.1457	0.9678
	25	–2.3343	–0.9907	0.7919
ΔM_t^w	5	0.4572	3.4546	0.9181
	10	–2.6134	3.5966	0.9586
	15	–3.966	1.2937	0.6114
	20	–5.222	–0.9814	0.3359
	25	–7.8793	–3.0964	0.6511
ΔM_t^{NaCl}	5	0.0348	0.7448	0.7974
	10	0.9801	1.5351	0.8182
	15	2.164	1.8184	0.7404
	20	2.7431	2.1372	0.7334
	25	2.8593	2.6193	0.7868

R^2 calculated from Equation 9 were obtained in most of the brine concentration levels, indicating a strong linear relationship for these brine concentration levels.

In fact, parameters in Equations 8 and 9 have similar physical meaning. D_e values in Equation 8 and k_2 values in Equation 9 are associated with the effective diffusion rate of water and salt, and K values in Equation 8 and k_1 values in Equation 9 can describe what happened at the initial stage of the brining. However, both equations are indispensable to describe the process. The former described how the meat liquid phase concentrated, whereas the later described how the process yield developed.

CONCLUSIONS

During the brining of rabbit meat, mass transfer (total, water and sodium chloride weight changes) and mass transfer kinetics parameters (k_1, k_2, D_e and K value) were significantly affected by the salt concentration. When salt concentration increased, the total weight changes and water weight changes decreased, whereas the sodium chloride weight changes increased. Higher brine concentrations resulted in a higher degree of protein denaturation and consequently led to lower process yields. Samples treated with higher brine concentrations obtained lower brining kinetic parameter values for total weight changes and water weight changes, whereas higher values were obtained for sodium chloride weight changes.

A mathematical model for rabbit meat (*Longissimus dorsi*) brining operation in 5 brines (5, 10, 15, 20 and 25% NaCl [w/w]) predicting the changes in meat weight, meat water and salt content and meat liquid phase composition and concentration was established. However, there may be some difference between *Longissimus dorsi* and other parts of the carcass, such as foreleg and hind leg. So, further study into brining of these parts and whole rabbit is needed before a final mathematical model can be fully established and proved.

Acknowledgements: The authors gratefully acknowledge financial support from the Special Public Welfare Industry (Agriculture) Research Program of China (Grant N°. 201303144), the National Rabbit Industry Technology System Programme (Grant N°. CARS-44D-1) and Chongqing Science and Technology Commission (cstc2014pt-gc8001). Part of the study was presented in a poster at the 11th World Rabbit Conference.

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