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Mass Transfer during Salting and Desalting Processes of Chinese Cabbage

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Abstract

The diffusion phenomena of water, solid and reducing sugar in Chinese cabbage during salting (50°C, 25% salt solution) and desalting (50°C, distilled water) were investigated. Water loss and solid gain during salting were rapid in the first 6hrs and then almost leveled off. After 24hrs of salting, water loss and solid gain in 100g of initial wet Chinese cabbage were 33.35g and 6.26g respectively. Moisture content was changed from 94.29% to 83.11% during 24hrs of salting. The reducing sugar concentration was also changed from 29.2 mg/ml to 6.5mg/ml, which was linearized as a function of the square root of salting time and showing that $Y=30.1841-5.0269\sqrt{t}$. After 24hrs salting, water gain and solid loss during desalting were rapid in the first 4hrs and then increased linearly. After 12hrs of desalting, the water gain and solid loss in 100g of initial wet Chinese cabbage were 20.82g and 9.14g respectively. The amount of solid loss after 12hrs desalting was higher than that of solid gain after 24hrs salting due to the diffusion of solute presented initially in the Chinese cabbage during salting and desalting. The concentration of salt in Chinese cabbage after 12hrs desalting was 2.98% which was a suitable salt concentration for the preparation of Kimchi. At this time, the concentration of reducing sugar was only 1.6mg/ml. The linear regression equation of reducing sugar concentration during desalting was $Y=6.7854-1.5992\sqrt{t}$.

Key words : mass transfer, salting, desalting, Chinese cabbage

INTRODUCTION

There are two types of salting methods, such as brine salting and dry salting. When salt solution or dry salt are used as salting agents, this gives rise to two simultaneous flows. Solute (solid) diffuses from the salting agent into the Chinese cabbage and water diffuses out of the Chinese cabbage into the salting agent due to the differences in osmotic pressures between the inter-cell of Chinese cabbage and the salting agent, in which the natural cell wall acts as a semi-permeable membrane[1] ; while direct opposition flows arise during the desalting process[2]. In general, it has been shown that the water loss and solid gain in salting foods are increased by increasing salt concentration, salting time, temperature, solution/food ratio, surface area of the food, and purity of osmotic agent[3-5].

When brine salting, Chinese cabbage is dipped into a 15% (w/v)-saturated brine concentration for 3 to 5 hrs, while dry salting is directly sprayed over the surface in the amount of 5~7% (w/w) of Chinese cabbage for 12hrs, to adjust 3% of salt concentration in Chinese cabbage[6]. Although diffusion of salt in foods such as pork, beef, fish and cheese has been studied by many workers[7-10], relatively few data are available for vegetable foods[11-13].

The objectives of this study were to investigate the diffusion phenomena of water, salt and reducing sugar during salting and desalting of Chinese cabbage.

MATERIALS AND METHODS

Materials

Chinese cabbages (*Brasica pekinensis* R.) obtained from the 1992 harvest were used in this study. The moisture content of the Chinese cabbages was 94.29%. The average height, diameter and weight

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of the cabbages were 27.80cm, 11.40cm and 2.21kg, respectively. Commercial bay salt was obtained from a local supermaket as a salting agent.

Experimental design

This experiment was conducted at high temperature (50° C) and salt concentration (25%, w/v) to maximize the leaching of reducing sugar (fermentable sugar) from Chinese cabbage during salting and desalting, which retarded the subsequent fermentation process and also reduced the final titratable acidity of Kimchi.

Salting and desalting processes

For the salting process, a whole Chinese cabbage was divided into ten parts and then trimmed to adjust to 100g of wet weight. The ten parts were totally immersed in a 1 liter beaker containing 500ml of salt solution (25%, w/v). After that, the beaker was covered with aluminium foil and maintained at 50° C, using an incubator, for a desired length of salting time. When the Chinese cabbages were removed from the salt solution, they were rinsed for a few seconds to remove excess salt, placed on filter paper to remove excess water, and weighed.

For the desalting process, 24hrs of salting Chinese cabbages were totally immersed in a 2 liter beaker containing 1 liter of distilled water. The beaker was also covered with aluminium foil and then maintained at 50° C. When the Chinese cabbages were removed from the distilled water, they were placed on filter paper to remove excess water and weighed.

Moisture content

Moisture content was determined after drying of Chinese cabbages using a cabinet dryer at 105° C for 12hrs.

Salt concentration

Salt concentration was determined by titration with silver nitrate[14].

Reducing sugar concentration

Reducing sugar concentration was determined by the dinitrosalicylic acid (DNS) method[15]. All experimental measurements were replicated two times.

Salting and desalting kinetics

For the unsteady state Fickian diffusion model to exactly apply, it is necessary that external solution concentrations remain constant, the material has a uniform thickness or radius, and external diffusion resistance is negligible compared to internal diffusion resistance. The conditions of this experiment are not met in all cases.

Therefore, the water loss (WL) and solid gain (SG) during the salting process can be determined by gravimetric measurement[16]. If it is assumed that under the conditions used, the solutes present initially in the Chinese cabbages will not diffuse against the total solids concentration gradient into the concentrated salt solution.

The water loss and solid gain in Chinese cabbage can be defined as following equations, respectively.

$$WL = \frac{(WWO) - (TW - WS)}{(WSO + WWO)} \times 100\ \text{(g/100g initial wet Chinese cabbage)} \quad (1)$$

$$SG = \frac{(WS - WSO)}{(WSO) - (TW - WWO)} \times 100\ \text{(g/100g initial wet Chinese cabbage)} \quad (2)$$

Where, WWO = initial water weight (g), TW = total weight after salting (g), WS = total solid weight after salting (g), and WSO = intial solid weight (g).

For the linearization of the above equations, mass balance on water movement inside the Chinese cabbage can be written as :

$$WL = WL_\infty - WS \quad (3)$$

Where, WL_∞ = water loss at equilibrium and WS = water that can diffuse out, but which remains inside the Chinese cabbage at time t.

The relationship between WL and WS can be represented by a parameter K.

$$K = \frac{WL}{WS} \quad (4)$$

A parameter K can be proposed in terms of time (t) and a constant (S_1) based on the rate of water loss is only a function of time.

$$K = S_1 t \quad (5)$$

Equation (1) can be linearlized by the following equation :

$$\frac{t}{WL_{exp}} = \frac{1}{S_1(WL_\infty)} + \frac{t}{WL_\infty} \quad (6)$$

Similarly, equation (2) can be linearized by the following equation :

$$\frac{t}{SG_{exp}} = \frac{1}{S_2(SG_\infty)} + \frac{t}{SG_\infty} \quad (7)$$

Where, SG_∞=solid gain at equilibrium and S_2= constant related to the rate of solid gain to the Chinese cabbage.

The equilibrium water loss and solid gain of Chinese cabbage were measured after 48hrs of salting.

For the desalting process, water gain (WG) and solid loss (SL) in Chinese cabbage can be defined by the following equations.

$$WG = \frac{(WWD - WW)}{(WSO + WWO)} \times \text{100 (g/100g initial wet Chinese cabbage)} \quad (8)$$

$$SL = \frac{(WS - WSD)}{(WSO + WWO)} \times \text{100 (g/100g initial wet Chinese cabbage)} \quad (9)$$

Where, WWD=total water weight after desalting (g), WW=total water weight after specific salting process (g), WS=total solid weight after specific salting process (g) and WSD=total solid weight after desalting (g).

The equilibrium water gain and solid loss of Chinese cabbage for the linearization of equations (8) and (9) were measured after 24hrs of desalting.

The mass transport coefficients (K) for salt and reducing sugar concentration (C) in Chinese cabbages are determined from the slope the C versus $(t)^{0.5}$ curves in following equation.

$$C = K(t)^{0.5} \quad (10)$$

Where, unit of t is hr.

RESULTS AND DISCUSSION

Salting process

Water loss and solid gain of Chinese cabbage during salting (50°C, 25% salt solution) as a function of time are shown in Fig. 1. Water loss was rapid in the first 6hrs and increased slowly thereafter. The solid was also gained very early in the process and then almost leveled off. The initial region of the plots is attributed to the adsorption of salt molecules onto the surface of Chinese cabbage. The changing Chinese cabbage solid content due to the uptake of solid alters the driving force for water flow beyond that due to the diffusive loss of water alone. The linear regression models, using equations (6) and (7), were able to successfully predict the whole salting process up to the equilibrium point. Additionally, experiments that proceeded faster had higher values of S in equation (5), which indicates a higher diffusion of material per unit time[5]. The linear regression equations of water loss and solid gain were $t/WL_{exp}=0.0303t+0.0215$ and $t/SG_{exp}=0.1495t+0.2242$, respectively.

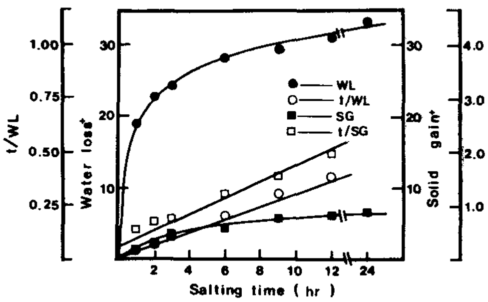

Fig. 1. Water loss and solid gain of Chinese cabbage during 50°C salting in 25% salt solution.

† Units of water loss and solid gain are g water loss/100g initial wet Chinese cabbage and g solid gain/100g initial wet Chinese cabbage, respectively.

Linear solid lines are predicted by equation (6) and (7).

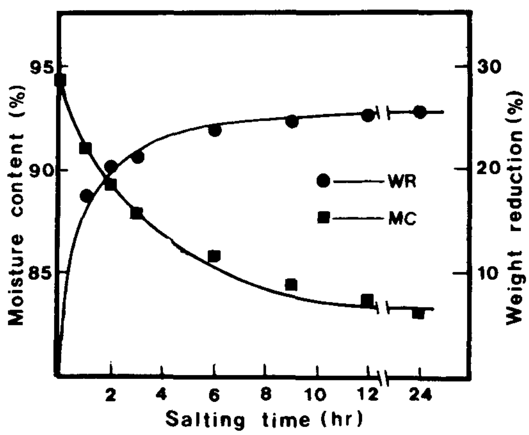

Fig. 2. Moisture content and weight reduction of Chinese cabbage during 50°C salting in 25% salt solution.

Regression coefficients for the fits were $r \geq 0.9744$. This meant that equations(6) and (7) were highly fitted to the experimental data.

Moisture content and weight reduction of Chinese cabbage during salting as a function of time are shown in Fig. 2. The moisture content was gradually decreased from 94.29% to 83.11% during the 24hrs salting process. Weight reduction was drastically reduced in the first 6hrs of the salting process and then slowly reduced as evidenced by the flattening of the curve. The amount of water loss is much greater than that of solid gain, showing that the net result is the weight reduction.

The salt and reducing sugar concentration in Chinese cabbage as a function of the square root of salting time are shown in Fig. 3. The linear regression equations of salt concentration and reducing sugar concentration in Chinese cabbage were $Y=1.5390\sqrt{t}+2.8770$ and $Y=30.1841-5.0269\sqrt{t}$, respectively.

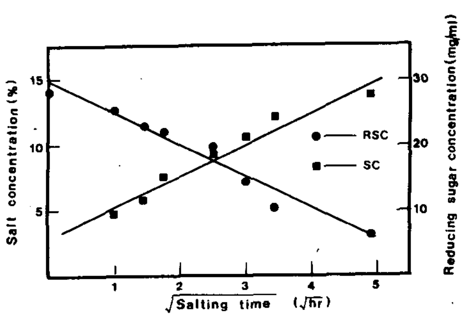

Fig. 3. Salt and reducing sugar concentrations of Chinese cabbage during 50° C salting in 25% salt solution.

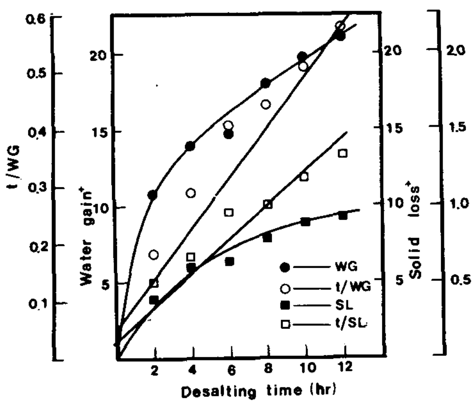

Fig. 4. Water gain and solid loss of 24 hrs salting Chinese cabbage during 50° C desalting in a distilled water.

+ Units of water gain and solid loss are g water gain/100g initial wet Chinese cabbage and g solid loss/100 g initial wet Chinese cabbage, respectively.

Linear solid lines are predicted by modification of equation(6) and (7).

Regression coefficients for the fits were $r \geq 0.9598$, which also meant that equation(10) was highly fitted to the experimental data. The linearity of plots indicates that internal diffusion is the rate determining process[16]. Although the K values in equation(10) do not have the normal dimensions for rates and so are not actual rate constants, their relative values, under approximately similar conditions, should be significant as rate parameters.

Desalting process

After 24hrs of salting, water gain and solid loss of Chinese cabbage during 50° C desalting in a distilled water as a function of desalting time are shown in Fig. 4. Direct opposition flows occured during the desalting process in comparison with the salting process. Therefore, solid diffuses out of the Chinese cabbage, and water diffuses from distilled water into the Chinese cabbage during desalting. As previously mentioned, water loss and solid gain in salting were rapid early in the process and then almost leveled off. While, water gain and solid loss in desalting were linearly increased until 12hrs after increasing rapidly in the first 4hrs. The percentage of recovery water weight after 24hrs desalting was 88.30%(w/w) per initial water weight in Chinese cabbage. In contrast, the amount of solid loss after 12hrs desalting is higher than that of solid gain after 24hrs salting, due to the leaching of solute presented initially in the Chinese cabbage during salting and desalting processes. The linear regression models for water gain and solid loss during desalting were $t/WG_{exp}=0.0445t+0.0407$ and $t/SL_{exp}=0.1084t+0.0934$, respectively. Regression coefficients for fits were $r \geq 0.9288$, which still highly fitted to the experimental data.

During desalting, moisture content and weight increase of 24hrs salting Chinese cabbage as a function of time are shown in Fig. 5. The moisture content was gradually increased from 83.11% to 96.25% during 12hrs desalting. The moisture content after 12hrs desalting was over the initial moisture content(94.29%) in spite of 86.35% recovery by water weight,

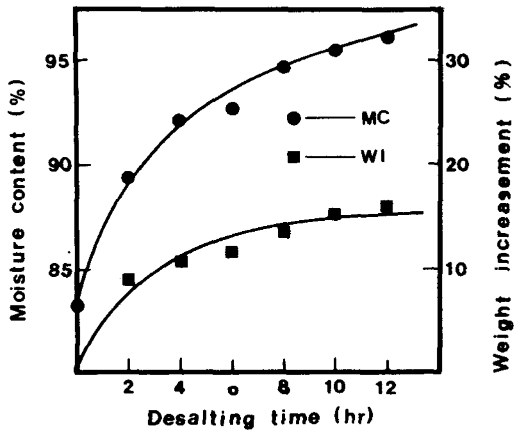

Fig. 5. Moisture content and weight increase of 24hrs salting Chinese cabbage during 50°C desalting in a distilled water.

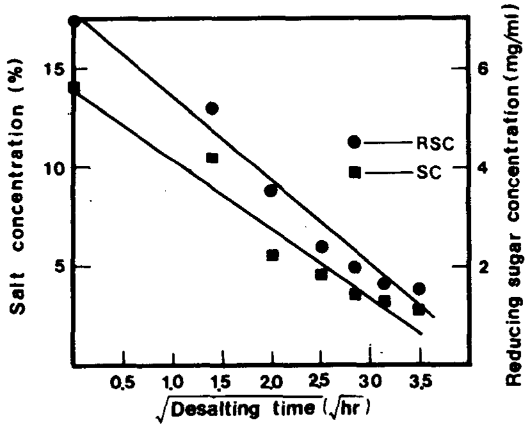

Fig. 6. Salt and reducing sugar concentrations of 24hrs salting Chinese cabbage during 50°C desalting in a distilled water.

which was due to the diffusion of solute presented initially in the Chinese cabbage during processing as previously mentioned. The rate of weight increase during desalting was a lower value than that of weight reduction during the salting due to the leaching of solute and partial recovery of water in Chinese cabbage during the salting or desalting process.

During desalting, the salt and reducing sugar concentrations in 24hrs salting Chinese cabbage as a function of the square root of desalting time are shown in Fig. 6. The linear regression models for salt and reducing sugar concentrations were $Y=13.6179-3.4054\sqrt{t}$ and $Y=6.7854-1.5992\sqrt{t}$, respectively. Regression coefficients for the fits were $r\geq0.9651$. After 12hrs of desalting, the salt concentration in Chinese cabbage was 2.98% which was a suitable salt concentration for the preparation of Kimchi. After 24hrs salting and then 12hrs desalting processes, the quantity of reducing sugar concentration (1.6mg/ml) in Chinese cabbage was very small compared to initial reducing sugar concentration (29. 2mg/ml), which retarded the subsequent fermentation process and also reduced the final titratable acidity of Kimchi.

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배추의 염절임 및 탈염 공정중 물질이동

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요 약

배추의 염절임(50°C, 25% 소금용액) 및 탈염(50°C, 증류수) 과정중 침지시간에 따른 물질이동을 수분흡수 또는 유출, 소금유출 또는 흡수 및 환원당유출로써 조사하였다. 염절임 과정중 수분유출과 소금흡수는 초기 6시간 침지과정에서 빠르게 이루어진 후 증가현상이 둔화되었다. 24시간 염절임 과정 후 초기 100g 배추무게당 수분유출과 소금흡수는 각각 33.35g과 6.26g이었다. 염절임과정중 수분함량은 94.29%에서 83.11%로 줄어들었다. 환원당농도 역시 29.2mg/ml에서 6.5mg/ml로 낮아졌으며, 침지시간(hr)의 평방근을 이용한 직선식은 $Y=30.1841-5.0269\sqrt{t}$이었다. 24시간 염절임 한 후 탈염과정에서의 수분흡수와 소금유출은 초기 4시간 침지과정에서 빠르게 이루어진 후 직선적으로 계속적인 증가현상을 나타내었다. 12시간 탈염과정 후 초기 100g 배추 무게당 수분흡수는 20.82g이었으며, 소금유출은 9.14g이었다. 탈염과정에서의 소금유출이 염절임과정의 소금흡수보다 높은 이유는 염절임 및 탈염과정에서 배추의 고형분 유출에 기인된 것이었다. 12시간의 탈염공정으로 김치 제조시 배추의 적정 소금농도인 3%로 낮출수 있었다. 이때의 환원당농도는 1.6mg/ml로 낮아졌으며, 침지시간의 평방근을 이용한 직선식은 $Y=6.7854-1.5992\sqrt{t}$로써 염절임 공정의 기울기값(-5.0269)과 비교할때 탈염공정에서의 환원당 겉보기 유출속도는 낮았다.