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Effects of Salt Addition in Sugar Based Osmotic Dehydration on Mass Transfer and Browning Reaction of Carrots

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Abstract

Mass transfer characteristics during osmotic dehydration of carrots were studied as functions of immersion temperature and time, and sugar and salt concentrations. The effect of osmotic dehydration on the degree of browning of air-dried carrots was also evaluated. Increasing the immersion temperature and time, sugar concentration, and salt addition increased water loss, sugar gain, molality and rate of dehydration. The water loss and increases in solids, and molality were rapid in the beginning of the process and then increased slowly during remainder of the process. Increasing 1 or 2% salt concentration in the 40°Brix sugar solution at 60°C increased water loss and solid gain. Salt addition was not able to significantly affected on water loss and solid gain compare to temperature (40~80°C) and sugar concentration (20~60°Brix) changes due to the low salt concentration. A minimum degree of browning of the air-dried carrots (O.D. = 0.048) could be achieved using binary solutions (40°Brix sugar solution with 2% salt addition) with 24 min of immersion time compared to control (O.D. = 1.308) or blanching with 24 min of immersion time (O.D. = 0.174).

Key words: carrot, osmotic dehydration, browning reaction, mass transfer

INTRODUCTION

Osmotic dehydration is a water removal process in which foods, such as fruits and vegetables, are placed into concentrated solutions of soluble solutes causing higher osmotic pressure and lower water activity (1). The driving force for water removal is the concentration gradient between the osmotic solution and the inter-cellular fluid, while the plant cells act as a semi permeable membranes. Since the membrane is only partially selective, there is always some solute diffusion into the food. Therefore, osmotic dehydration is considered to be a simultaneous water and solute counter-diffusion process (2,3). Osmotic dehydration is affected by several factors such as the osmotic agent, solute concentration, temperature, time, size, shape, and tissue compactness of the material (4). Many researchers have analyzed the characteristics of mass transfer during osmotic dehydration using techniques such as the development of a quantitative model based on a simple theory of equilibrium using polynomials, a model using general power law equation, hyperbolic equation, and the theory of diffusion and equilibrium (5-10).

Various osmotic agents such as sucrose, glucose, fructose, corn syrup and sodium chloride, etc., have been used for osmotic dehydration. Generally, sugar solutions are used for fruits and salt for vegetables. Osmotic dehydration is a gentle process and results in a product with good color, texture and flavor (11-13). Osmotic dehydration inhibits the action of polyphenol oxidase and retards loss of volatile flavor constituents during dehydration. It can be used in conjunctions with other methods of drying such as air drying, vacuum drying and freeze drying (14). Osmotic dehydration has been carried out by different workers at a wide range of temperature varying from 25 to 85°C. The inactivation of enzymes was achieved by the blanching effect in high temperature (80~85°C) used for osmotic dehydration (15).

The aims of this study is to analyze the mass transfer during osmotic dehydration of carrots in sugar alone and salt added solutions as a function of sugar and salt concentrations, immersion time and temperature, and the effect of osmotic dehydration on browning inhibition of air dried carrots.

MATERIALS AND METHODS

Materials

Carrots (*Dancus carrot* L. *vav sativa* D.C.) obtained from the 2003 harvest were used in this study. The average moisture content of the carrots was 89.9% on a wet basis.

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The carrots were sliced into 2 mm thickness using a food processor (Sunbeam, Oskar, Japan). Commercial white sugar and salt were obtained from a local supermarket for use as the osmotic agents.

Osmotic dehydration

Approximately 50 g batches of wet carrot slices were placed into a 1 liter beakers containing 250 mL of sugar solution (20~60°Brix) and salt (0~2%, w/v) solutions and agitated at constant temperatures (40~80°C) in a water bath for pre-determined lengths of immersion times (4~24 min). When the carrot slices were removed from the osmotic solutions, they were rinsed for a few seconds to remove excess osmotic agents and placed on filter paper to remove excess water and weighed. All experimental data are means of three replications.

Air dehydration

For air dehydration, carrots were placed on a tray with a 0.4 g/cm^2 tray load and dried at 70°C with 3 m/s air velocity immediately following osmotic dehydration to a 4% moisture content.

Moisture content

Moisture content was determined using a drying oven at 105°C until the samples reached a constant weight.

Browning degree

The degree of browning was determined by putting a 1 g of the air-dried carot powder that had been passed through a 48 mesh screen into a 250 mL flask containing 40 mL of a 10% trichloroacetic acid solution. The flask was covered with parafilm and allowed to remain at room temperature for 2 hr with occasional shaking in a dark room. After the solution was filtered through tyro No. 2 filter paper, the O.D. of the filtrate was read at 420 nm using a spectrophotometer (Shimadzu double beam spectrophotometer, UV-200S) (16).

Kinetics of osmotic dehydration

The water loss (WL) and solids gain (SG) can be determined by gravimetric measurement assuming that the solutes present initially in the carrots will not diffuse against the total solids concentration gradient into the concentrated osmosis solution (17). The total wet weight (TW) of the carrot was determined upon removal from the osmotic solution and total solid weight (WS), initial solid (WO), and initial water (WW) were determined by the drying oven method.

$$WL = \frac{(WW)-(TW-WS)}{(WO+WW)} \times 100 \ (\textit{g water loss/ 100 initial wet carrot}) \quad \cdots\cdots (1)$$

$$SG = \frac{(WS)-(WO)}{(WO+WW)} \times 100 \ (\textit{g solid gain/ 100 g initial wet carrot}) \quad \cdots\cdots (2)$$

A rate parameter, K, can be defined by the molal concentration of sugar in the water remaining in the carrot.

$$Molality = Kt^{0.5} \quad \cdots\cdots (3)$$

where,

$$Molality = \frac{(Sugar\ gain)_{t=i}}{(Water\ loss)_{t=0} - (Water\ loss)_{t=i}} \times \frac{1000}{MW\ of\ sugar} \ (\textit{sugar moles/kg water}) \quad \cdots\cdots (4)$$

RESULTS AND DISCUSSION

Immersion temperature effects

The effects of immersion temperature at 40°Brix sugar solution on water loss and solid gain of carrots are shown in Fig. 1. Water loss and solid gain were rapid in the beginning of process and proceeded slowly thereafter. Increasing the temperature of sugar solutions increased water loss and solid gain, which would indicate that internal diffusion is the determining step in osmotic dehydration (17). After 24 min of immersion, water loss and solid gain in 100 g wet carrot at 40, 60 and 80°C were 17.0, 23.5 and 36.2 g water loss and 6.2, 10.3 and 12.3 g solid gain, respectively. In the case of water loss, the temperature affects were greater between 60°C and 80°C than between 40°C and 60°C, while solid gain is more

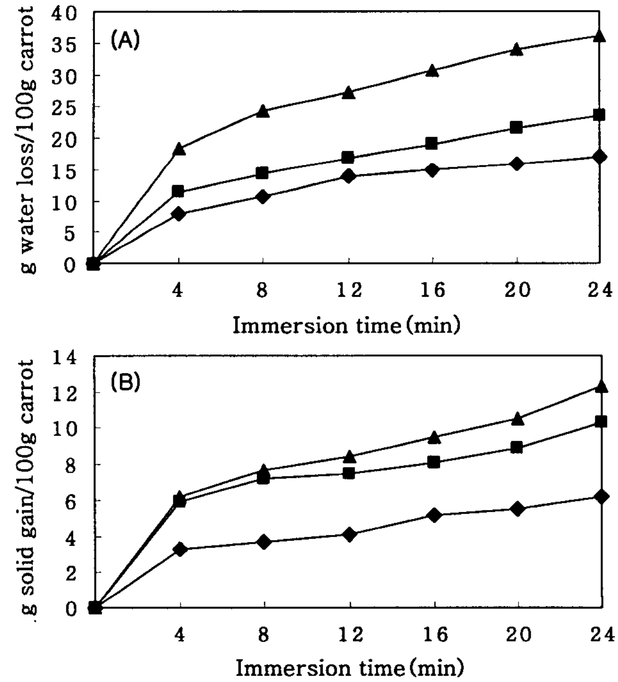

Fig. 1. Water loss (A) and solid gain (B) as a function of immersion temperature and time at 40°Brix sugar solution.
-◆- : 40°C, -■- : 60°C, -▲- : 80°C.

affected by temperatures between 40°C and 60°C than between 60°C and 80°C.

Sugar concentration effects

Fig. 2 shows the effects of sugar concentration at 80°C on water loss and solid gain of carrots. Water loss and solid gain increase as the sugar concentration increases. The amount of water loss is much greater than that of solid gain. The mechanism of osmotic dehydration involves an initial period of solid gain and water loss due to surface adsorption, followed by internal diffusion which appears to be the rate controlling step (17). After 24 min of immersion time, water loss and solid gain of 100 g wet carrot at 20, 40 and 60°Brix were 15.1, 36.2 and 49.8 g water loss and 5.7, 12.3 and 15.5 g solid gain, respectively.

Salt addition effects

The effects of salt addition to sugar solutions at 60°C and 40°Brix are shown in Fig. 3. Salt is an excellent osmotic agent for vegetables but its use in fruits is limited since a salty taste is imparted to the food (13). Increasing the 1 or 2% salt concentration increased water loss by driving force increment and solid gain, which was not significantly affected owing to the low value of salt concentration changes on water loss and solid gain compared to temperature and sugar concentration changes as shown in Fig. 1 and 2. The kind of osmotic agent used and hence its molecular weight or ionic behavior affect the kinetics of water loss, solid gain and equilibrium water content (18). At low sugar concentrations, salt gain increases linearly as a function of salt concentration. At high sugar concentrations, salt gain is independent of salt concentration and remains very low (19).

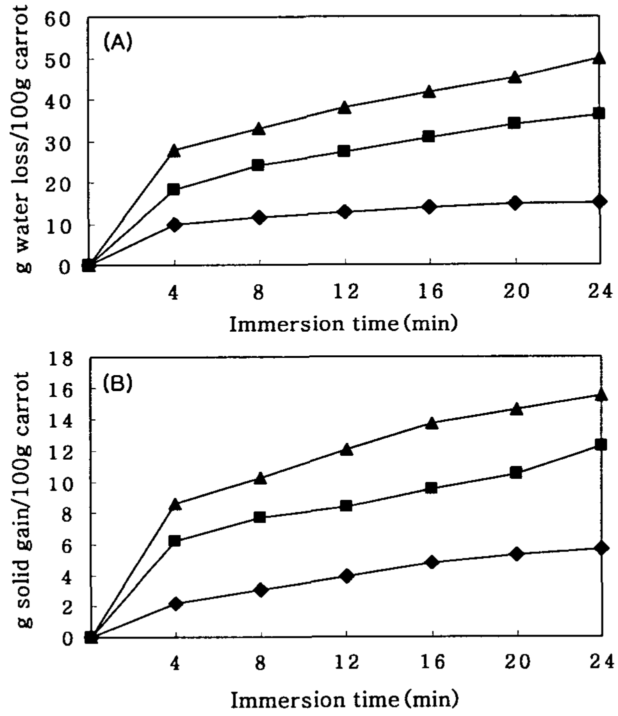

Fig. 2. Water loss (A) and solid gain (B) as a function of sugar concentration and immersion time at 80°C.
-◆- : 20°Brix, -■- : 40°Brix, -▲- : 60°Brix.

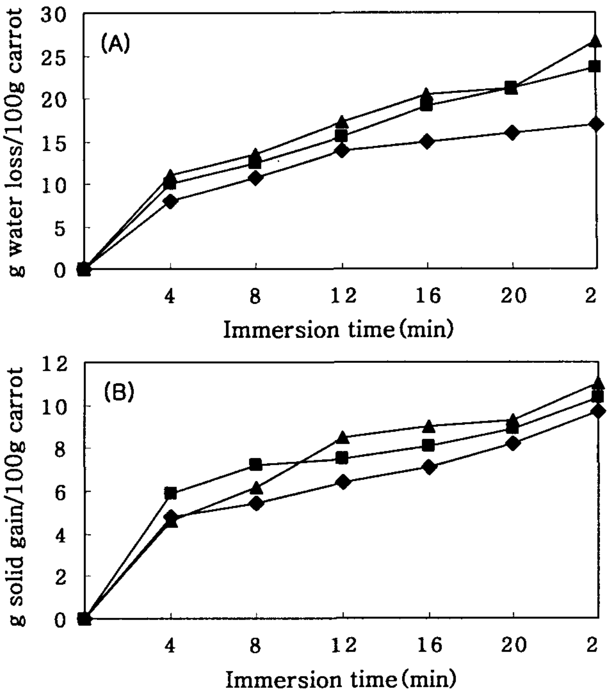

Fig. 3. Water loss (A) and solid gain (B) as a function of NaCl concentration and immersion time at 60°C, 40°Brix sugar solution. -◆- 0%, -■- 1%, -▲- 2%.

Sugar molality and rate parameter

Sugar molality was increased as the immersion temperature, time and sugar concentration increased, which means water loss and solid gain were increased as shown in Fig. 4. To establish the time dependence of the osmotic dehydration, the molal concentration of sugar in the carrots more accurately describes the overall behavior and kinetics of the process. The K values were determined from the slopes of plots of sugar molality against the squre root of the immersion time in minutes as shown Table 1. The values of parameter K increased as the immersion temperature and sugar concentration increased. The linearity of the plots ($0.908 < r < 0.988$) indicated that internal diffusion is the rate determining process (20).

Browning degree

Fig. 5 shows how the browning reaction is affected by osmotic dehydration with the addition of salt and blanching prior to 70°C air drying to a 4% moisture content. As the blanching time increased, the degree of browning decreased almost linearly. In the case of effects of osmotic dehydration, however, the browning degree of carrots was

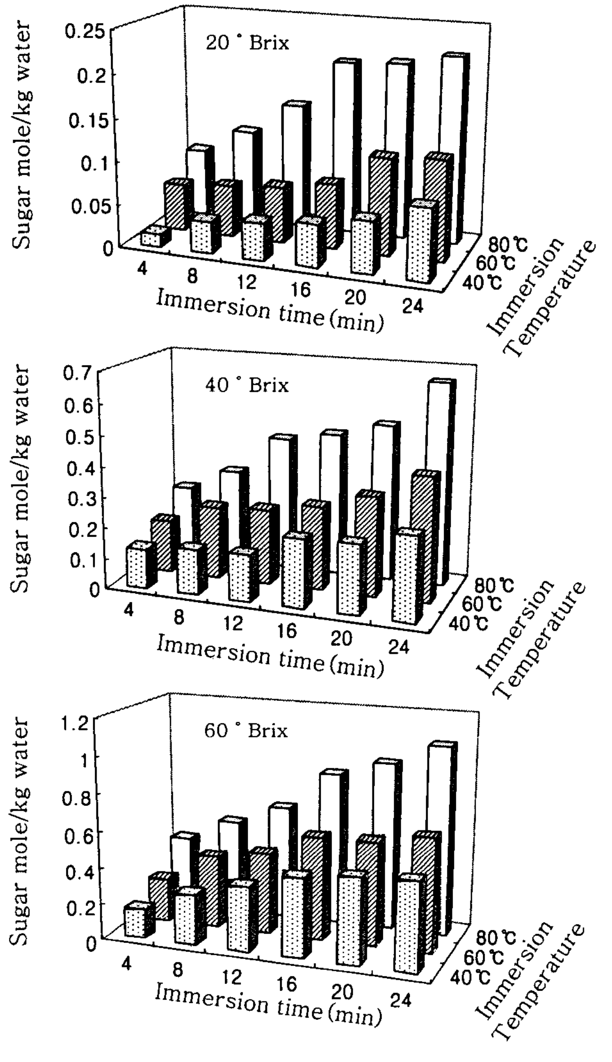

Fig. 4. Molality of sugar as a function of immersion temperature, time and °Brix of sugar solution.

Table 1. Value of rate parameter K as a function of °Brix and temperature of sugar solution

	40°C		60°C		80°C	
	K[1]	r	K	r	K	r
20°Brix	0.020	0.967***[2]	0.023	0.908**	0.053	0.978***
40°Brix	0.049	0.940**	0.071	0.948**	0.136	0.931**
60°Brix	0.114	0.988***	0.131	0.982***	0.230	0.987***

[1] Sugar mole/kg water · $\mathrm{min}^{0.5}$.
[2] **$p<0.01$, ***$p<0.001$.

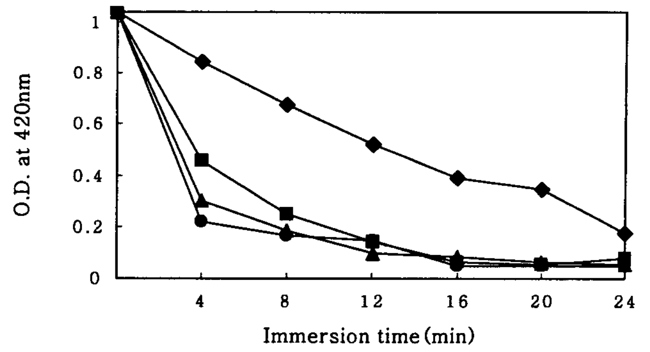

Fig. 5. Effect of blanching and osmotic dehydration at 80°C on browning reaction of carrot dried to 4% (wet basis) using cabinet drier with 70°C.
-◆- : Blanching, -■- : 40°Brix, -▲- : 40°Brix with 1% salt, -●- : 40°Brix with 2% salt.

sharply decreased and then almost leveled off during immersion time. Osmotic and air dried carrots had lower browning degrees than blanched and air dried carrots at the same processing temperature, 80°C. The effects of adding salt to the sugar solution on browning reduction were significantly affected in the first stage of osmotic processing. Minimum browning degree of dried carrots (O.D. = 0.048) could be achieved using binary solutions (40°Brix sugar solution with 2% salt addition) with 24 min of immersion time compared to control (O.D. = 1.308). And the O.D. of blanching with 24 min of immersion time and then air dried carrots was 0.174.

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