American Journal of Food Technology

ISSN 1557-4571

Academic Journals Inc.

www.academicjournals.com

American Journal of Food Technology 6 (6): 483-491, 2011
ISSN 1557-4571 / DOI: 10.3923/ajft.2011.483.491

Osmotic Dehydration as a Factor in Freezing of Tomato

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ABSTRACT

The objectives of this study were to investigate the influence of osmotic solutions and their concentration on mass transfer and observe any effect on lycopene content, color and melting temperature (T_m) of tomatoes. The tomato pieces were osmosed in maltose (35, 50%), sucrose (35, 60%) and sorbitol (35, 60%), solutions for 2 and 6 h. Sucrose and sorbitol were highly effective in reducing water content in tomatoes, compared to maltose. Highest solid gain was found by using sorbitol. The 60% of sucrose and sorbitol caused the reduction of lycopene content and alternation of color. The evaluation of T_m was depended on osmotic agents and could be related with the solid mass fraction. The 50% was recommended for the frozen tomatoes, compared to sucrose and sorbitol.

Key words: Osmotic solution, mass transfer, tomato, freezing, property

INTRODUCTION

Osmotic Dehydration (OD), immersing food samples in osmotic solutions (such as sucrose, glucose, corn syrup, maltose, sorbitol, etc.) is a viable process for the partial removal of water from cellular material (such as fruits and vegetables) without a phase change. The water from the food flows towards the solution and, in an inverse sense, the solids from the solution to the product. The type of osmotic agents always plays an important role in the osmotic dehydration affecting the mass transfer of water and solids (Tregunno and Goff, 1996; Panagiotou *et al*., 1999) and Product characteristics (Forni *et al*., 1997; Talens *et al*., 2003). The mass transfer is also depended on the nature of the plant tissue and the process variables (Lenart and Flink, 1984; Rahman and Lamb, 1990; Raoult-Wack *et al*., 1991; Kaymak-Ertekin and Sultanoglu, 2000; Giraldo *et al*., 2003; Mujica-Paz *et al*., 2003; Uddin *et al*., 2004).

The advantages obtained from osmotic dehydration include: providing the inhibition of enzymatic browning and preventing volatile flavoring loss; providing the required range of water and solute in food material to further processing; minimization of thermal stress; a reduction of energy input compared to conventional drying and freezing processes; enhancement of sensory quality; providing a "fresh-like" state of raw material as Intermediate Moisture Food (IMF), etc. It is often applied as a pretreatment to process certain food products, for example dried products (Chottanom and Phoungchandang, 2005; Lombard *et al*., 2008). Recently, many studies found a potential use of osmotic dehydration for limiting biological compound loss during further processing

(Shi *et al.*, 1999; Heredia *et al.*, 2009). For frozen products, it is an important pretreatment for fruit freezing (Forni *et al.*, 1997; Talens *et al.*, 2003). Low molecular weight sugars or sugar alcohol such as sorbitol and xylitol are often added to food systems to give plasticizing or cryostabilizing effects (Kim *et al.*, 2004). The osmotic dehydration presents clear advantages for preserving the quality of thawed products, showing preferable measured-quality of color, drip loss and texture.

The aim of this study was to apply the osmotic dehydration to tomato freezing. The influence of osmotic solution types on mass transfer and melting temperature (T_m; Differential Scanning Calorimetry (DSC) method) of tomato was analyzed. Other objectives were to monitor an alteration of lycopene content during osmotic dehydration and frozen product quality after freezing.

MATERIALS AND METHODS

Tomato: Tomato (*Lycopersicon esculentum* Mill) samples located in the north-eastern of Thailand were used. All tomatoes used in this study were delayed for less than 48 h in a refrigerator at 4°C. For purposes of analysis, two groups of tomatoes were established, a control group of fresh tomatoes and an osmosed group. The tomatoes in each group were peeled, deseeded and cut into 4 pieces and the Moisture Content (MC) (AOAC, 1990) of both groups was determined.

Dehydrofrozen procedure: The tomato pieces (180-200 g/container) in the osmosed group were soaked in three osmotic solutions with the concentration of 35 and 50% (w/w) for the maltose solution, 35 and 60% (w/w) for the sucrose solution and 35 and 60% (w/w) for the sorbitol solutions. An OD time was 2 and 6 h. The mass ratio of tomato and solution was 1:6. The temperature of solution and checking velocity was controlled at 35°C and 150 rpm, respectively. Each sample was drained and then vacuum packed in a poly ethylene pouch. Batches of the packaged samples were subjected to a conventional freezer at -18°C for 4 months.

Freezing time estimation: The fresh and the osmosed tomatoes, soaked for 6 h, were frozen (140-150 g for each group) to -18°C in an air blast freezer at -35°C (iRiNox New "HC" series, Italy). The evolution of the core temperature of samples was recorded by using a data logger to estimate the freezing time required to reduce the temperature of sample from 21 to -18°C (Karel *et al.*, 1975).

Melting temperature (T_m) determination: The fresh and the osmosed tomatoes with the solid mass fraction ranged from 0.05 to 0.50 were used. The onset melting temperature of the samples was determined by using a differential scanning calorimeter (Perkin-Elmer Pyris Diamond, USA). The instrument was calibrated for temperature and heat flow using distilled water and indium. Helium gas (99.99% purity) was used as the purge gas at a pressure of 20 lbs in^{-2} (flow rate 40.0 mL min^{-1}). The fresh control group tomatoes and the osmosed group tomatoes were weighed in 40 μL aluminum pan (PE NO 02190041). All samples were cooled with liquid nitrogen to -50°C, held for 3 min and then heated at 10°C min^{-1} with a sample size typically in the range of 6-8 mg.

Relationship between T_m and solid content values (mass fraction) was evaluated. The polynomial equation has been used to describe the correlation between T_m and water fraction of fresh tomato, r = 0.993 (Telis and Sorbral, 2002) and between the initial freezing point and water fraction of some fruits and vegetables (Dickerson, 1986). In this study, the T_m values of each tomato sample were related to solid content values (mass fraction) by using second-order polynomial equation as follows:

$$T_m = b_0 + b_1X_s + b_2X_s^2 \quad (1)$$

where b_0, b_1 and b_2 are the constant. X_s is the solid fraction.

Mass transfer estimation: The tomatoes were determined the mass transfer after osmotic dehydration process for 2 and 6 h. The parameters of mass transfer, Weight Reduction (WR), Water Loss (WL) and Solid Gain (SG), during osmotic process were estimated by using Eq. 2, 3 and 4, respectively and expressed in g per 100 g initial sample as follows:

$$WR = 100\left(\frac{m^{\circ} - m^{t}}{m^{\circ}}\right) \quad (2)$$

$$WL = 100\left[W^{(o)} - \left(W^{(t)} \times \frac{m^{(t)}}{m^{(o)}}\right)\right] \quad (3)$$

$$SG = 100\left[\left(S^{(t)} \times \frac{m^{(t)}}{m^{(o)}}\right) - S^{(o)}\right] \quad (4)$$

where $m^{(t)}$ and $m^{(0)}$ are the mass of tomato at time t and the initial mass of tomato, respectively. $W^{(0)}$ and $S^{(0)}$ are the initial water content (mass fraction) and solid content (mass fraction) of the tomato, respectively. $W^{(0)}$ and $S^{(t)}$ are the water content (mass fraction) and solid content (mass fraction) of the tomato at time t, respectively.

Color measurement: Color measurements of the 6 h osmosed tomatoes were performed by using a Minolta color meter (CR-300). The coordinates of the color CIE-$L^*a^*b^*$ of the tomato surface were obtained by reflection. L^*, a^* and b^* represent the lightness, redness and yellowness values, respectively.

Lycopene measurement: The lycopene content (mg g^{-1} total solids) of the 6 h osmosed tomatoes were spectrophotometrically determined on extracts in petroleum ether in triplicate at 505 nm (Gould and Gould, 1988) using a UV-Visible spectrophotometer (Milton Roy Spectronic 1201, USA). The lycopene content was quantified by using a standard curve of 95% purified lycopene (Sigma Chemical Co., St. Louis, USA) dissolved in petroleum ether.

Drip loss measurement: After thawing at 20°C in a temperature-controlled bath, each sample (6 h osmosed tomatoes) was removed from the pouch leaving behind the drip. The pouch containing the drip was then weighted. Drip loss was computed from the weight of drip and that of the sample and expressed as a percentage loss based on the initial sample weight.

Sensory attributes: To quantity the sensory attributes, the thawed samples were subjected to sensory analysers. The samples were subjectively rated by 16 sensory panels on the scale of 1-5 as follows: 1-very good; 2-good; 3-fair; 4-poor; 5-very poor.

Experimental design: A factorial in completely randomized design (2^3 factorial experiments) was used to evaluate the effect of osmotic solution type, concentration and OD time on the mass transfer

of tomatoes. A completely randomized design was used for the other experiment. Each experiment was conducted with three replications. The statistical analysis was processed by using software of the package program, SPSS version 14.0 (SPSS Inc., Thailand). Analysis of variance was performed by ANOVA procedures. Significant difference between experimental means was determined by using the Duncan's multiple range tests and the Paired sample T-test. A significance of differences was defined at $p<0.05$.

RESULTS AND DISCUSSION

Table 1 shows the physical and chemical properties of the sample tomatoes. The red and firm attribute (well developed) was used. The initial moisture content of fresh tomato varied from 93 to 96%. The weight and hardness values of the tomatoes were quite varied compared to other properties, especially the moisture content and soluble solids (measured by a hand refractometer). The moisture content, soluble solids and redness values were the major properties for choosing the tomato samples in order to control the variation affecting on mass transfer and product characteristics during osmotic dehydration.

Mass transfer parameters: Table 2 shows the effect of osmotic solutions and osmotic dehydration time on the mass transfer of the osmosed tomatoes. Each type of osmotic solutions had different potential to decrease the initial moisture content and to increase solid content of the osmosed

Table 1: Physical and chemical properties of fresh tomatoes

Properties	Mean±SD
Weight (g/tomato fruit)	70.89±8.68
Moisture content (g/100 g sample)	94.45±0.70
Lycopene (mg/100 g sample)	8.05±1.95
Soluble solid* (°Brix)	4.00
Color parameters	
Lightness (L*)	41.18±1.46
Redness (a*)	23.10±2.69
Yellowness (b*)	16.41±2.18
Hardness (g)	8.03+3.09

*Measured by using an ATAGO hand-held refractometer

Table 2: Mass transfer of water and solids of tomatoes during osmotic dehydration

Osmotic solutions	OD time (h)	MC*	WR*	WL*	SG*	WL/SG
35% Maltose	2	92.89±0.49^{e}	1.06±0.35^{a}	2.56±0.62^{a}	1.79±0.27^{a}	1.42±0.13^{a}
50% Maltose	2	91.46±0.26^{e}	10.54±0.62^{b}	12.07±0.17^{b}	1.53±0.27^{a}	8.01±1.02^{de}
35% Maltose	6	83.62±4.14^{d}	22.91±0.54^{c}	29.84±3.64^{c}	6.93±3.10^{bc}	4.30±0.07^{b}
50% Maltose	6	78.02±2.72cd	38.37±9.48^{ef}	47.08±6.42^{e}	8.71±3.44^{bcd}	5.40±3.82^{bc}
35% Sucrose	2	81.27±2.16^{cd}	29.46±8.12^{cd}	36.66±9.00^{cd}	7.20±1.11^{bc}	5.09±0.01^{bc}
60% Sucrose	2	76.24±4.34^{cd}	49.75±5.16^{g}	56.05±6.32^{f}	6.30±1.19^{bc}	8.90±0.28^{e}
35% Sucrose	6	75.02±2.47^{bc}	47.63±5.31^{g}	55.70±1.47^{f}	8.07±1.14^{bcd}	6.91±0.15^{cde}
60% Sucrose	6	68.07±7.86^{b}	67.18±0.64^{h}	73.07±0.34^{g}	5.89±0.37^{b}	12.42±0.46^{f}
35% Sorbitol	2	78.06±1.38^{cd}	31.78±4.41^{de}	41.44±3.78^{de}	9.65±1.05^{bcde}	4.30±0.06^{b}
60% Sorbitol	2	67.45±3.27^{b}	49.15±3.01^{g}	60.30±3.35^{f}	11.15±3.16^{cdef}	5.41±0.08^{bc}
35% Sorbitol	6	68.45±1.77^{b}	41.80±1.95^{fg}	56.07±1.64^{f}	14.27±0.34^{f}	3.93±0.03^{b}
60% Sorbitol	6	52.11±10.31^{a}	64.48±2.72^{h}	77.10±1.09^{g}	12.62±1.72^{ef}	6.11±0.08^{bcd}

*g/ 100 g sample, Different letters in a column indicate significant differences ($p<0.05$)

Table 3: The b*/a* values of osmosed tomatoes in maltose, sucrose and sorbitol solutions for 6 h osmotic dehydration

Osmotic solutions	Before OD	After OD	Sig. (2-tailed)*
35% Maltose	0.86±0.18	0.85±0.24	0.922
50% Maltose	0.66±0.11	0.65±0.17	0.800
35% Sucrose	0.67±0.07	0.57±0.05	0.132
60% Sucrose	0.70±0.02	0.59±0.04	0.024
35% Sorbitol	0.64±0.06	0.56±0.04	0.020
60% Sorbitol	0.67±0.07	0.62±0.06	0.013

*Paired samples T-test ($p<0.05$)

tomato. Sucrose and sorbitol solutions with 60% and 6 h soaking were the most effective agents for water removal from tomato tissue but the sorbitol promoted two times more solid gain into the tissue than that of sucrose, because of its low molecular size.

Sucrose and sorbitol solutions with a molecular weight of 342 and 182, respectively, showed a potential for water removal during osmotic dehydration, compared with a maltose solution with a molecular weight of 360.23. During osmotic dehydration, low molecular weight solutions had higher corresponding osmotic pressure (Saurel *et al.*, 1994), which could flavor plant cell plasmolysis and enhance water removal from tissue samples. In a similar result, Panagiotou *et al.* (1999) found that, glucose seems more effective than sucrose in the water loss and solid gain of apples, bananas and kiwi. The 40% glucose concentration gave a higher water loss and solid gain than a sucrose concentration at up to 50% of the same condition. Based on literature studied, it is known that the mass transfer rate in osmotic dehydration is influenced by the two major variables, process conditions (osmotic agent, concentration, temperature, medium velocity, contact time, etc.) and the structure of biological material.

Generally, higher solid gains into food tissue are not required in frozen fruits and vegetables because it adulterates the natural flavor of the products. Initially, maltose solution and sucrose solution should be recommended for tomato freezing. The samples with high WR and/or WL/SG values, soaked in 60% of sorbitol and sucrose, should not be frozen because of tissue shrinkage. Generally, loss of large amount of water and gain of small amount of solids into tissue lead to the tissue shrinkage. Therefore, 6 h osmotic dehydration using 60% of sorbitol and sucrose should be avoided for the tomato preparation before freezing.

Color parameters: Table 3 shows that the osmotic dehydration did not clearly affect the color of tomato osmosed in maltose solution (L^*, a^* and b^* values are not shown). However, lower values of the ratio of yellowness and redness (b^*/a^*) of osmosed samples were found, particularly decreasing in the b^*/a^* value of the osmosed samples in sucrose and sorbitol solutions. In this study, the increase of coordinates a^* was higher than the increase of coordinates b^*, contrasting to the color alternation of osmosed cherry tomato reported by Heredia *et al.* (2009). Generally, an increase of the chromatic coordinates a^* and b^* can be promoted to the concentration of the liquid phase and the pigments in the cellular tissue as a consequence of the osmotic dehydration.

Lycopene content: Figure 1 shows the effect of osmotic solutions on the lycopene retention as osmotic progress. Maltose (50% concentration) and sucrose (35% concentration) uptake in the tissue was the protective action of lycopene in osmotic dehydration, compared to sorbitol and sucrose with 60% concentration. The high concentration of sucrose and sorbitol solutions caused the reduction of lycopene content compared to the low concentration. One possible explanation may be that the

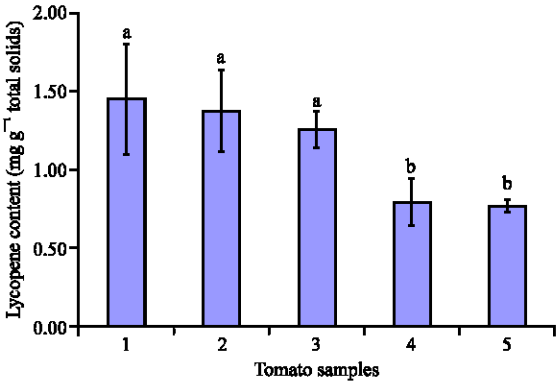

Fig. 1: Lycopene content of (1) fresh tomato and (2) osmosed tomatoes in 50% maltose, (3) 35% sucrose, (4) 60% sucrose and (5) 60% sorbitol solutions for 6 h osmotic dehydration. Different letters indicate significant differences ($p<0.05$)

Table 4: Influence of osmotic solutions on freezing time of tomatoes for 6 h osmotic dehydration

Osmotic solutions	Time to reduce temperature from 21 to -18°C (min)
Fresh tomato	19.25±0.95^{b}
35% Maltose	18.00+1.00^{ab}
50% Maltose	18.5±0.50^{ab}
35% Sucrose	17.33±0.56^{a}
60% Sucrose	17.70±1.15^{a}
35% Sorbitol	17.33±0.56^{a}
60% Sorbitol	17.50±1.00^{a}

Different letters indicate significant differences ($p<0.05$)

effect of high osmotic pressure causes tissue damage, inducing oxidation of lycopene. A similar result on the decrease of lycopene caused by a high concentration of salt solution (20%) was reported by Heredia *et al.* (2009). Maltose was reported to have the highest protective effect on chlorophyll stability during storage at -10°C for kiwi fruits (Torreggiani *et al.*, 1993) and on color and ascorbic acid stability of apricots (Forni *et al.*, 1997).

Freezing time and melting temperature (T_m): Table 4 shows the freezing time of osmosed tomatoes. The effect of osmotic solution on the freezing time could be observed. Even though small amount of time difference was detected. This is possibly due to the high rate of shock freezing and low volume of samples used in this study (Shock freezing mode can reduce the core temperature of samples to -18°C within 4 h depending on type, thickness, initial temperature, number and package of sample). The reduction of freezing time by osmotic solutions could be explained that, the super cooling phenomenon of water in tomatoes was influenced by the osmotic solids in the tissue which promoted heterogenous nucleation, thereby accelerating the nucleation process.

Figure 2 shows the on set melting temperature (T_m) of the tomato samples. The melting temperature of the tomatoes was shifted by the osmotic solutions and there solid fraction values. As expected, the melting temperature decreased with increasing solid content.

In the report of Baek *et al.* (2004), who were analyzing the starch-sugar melting temperature by DSC method, it was observed that the melting temperature decreased as proportional to molar concentration of sugar and that the differences among the sugars (monosaccharides, hexoses and

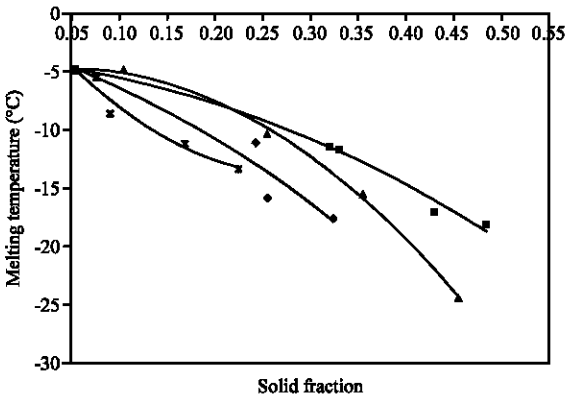

Fig. 2: Melting temperature (T_m) of fresh (▲) and osmosed (✖ maltose; ◆ sucrose; ■ sorbitol) tomatoes vs. solid fraction values

pentoses) were minor. However, the melting temperature data of osmosed tomato were not colligatively governed, showing a dependence on sugar structure.

Interestingly, the melting temperatures of the tomatoes osmosed in sucrose and maltose solutions were lower than that of the fresh tomatoes and the tomatoes osmosed in sorbitol solution, linking to unfrozen liquid level. Considering that the empirical Eq. 5 to 8 fitted well the experiment points of T_m of the fresh tomato (Eq. 5) and the tomato osmosed in maltose (Eq. 6), sucrose (Eq. 7) and sorbitol (Eq. 8) solutions, respectively.

$$T_m = -4.87 + 8.88X_s - 115.56X_s^2 \qquad (R^2 = 0.99) \tag{5}$$

$$T_m = -0.64 + 94.187X_s - 168X_s^2 \qquad (R^2 = 0.95) \tag{6}$$

$$T_m = -3.39 - 26.43X_s - 58.69X_s^2 \qquad (R^2 = 0.91) \tag{7}$$

$$T_m = -4.24 - 9.81X_s - 42.34X_s^2 \qquad (R^2 = 0.99) \tag{8}$$

In a similar study, Cornillon (2000) found the influence of solution concentration on the freezing point of an apple sample. They concluded that a change of the freezing point of dehydrated fruits and the associated enthalpy of crystallization was a function of the amount of sugar present in the fruit. Telis and Sorbral (2002) found that the melting point could be related with water fraction in tomato by using a second-order polynomial model as well.

Sensory attribute and drip loss: The frozen tomatoes tested were color, appearance, texture and overall acceptability. Figure 3 indicates sensory scores and drip loss values of the product frozen 4 months frozen-storage at -18°C. It is very clear from the results that the frozen tomato using maltose was most acceptable ($p<0.05$), because of the good appearance and low value of drip loss. The use of sucrose provided the highest drip loss that was not different to the control (fresh-treatment).

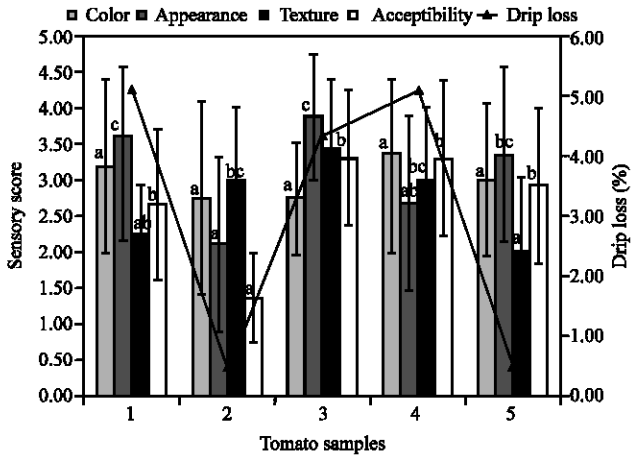

Fig. 3: Sensory scores and Drip-loss values of (1) fresh tomato and (2) osmosed tomatoes in 50% maltose, (3) 35% sucrose, (4) 60% sucrose and (5) 60% sorbitol solutions for 6 h osmotic dehydration. Different letters in each bar indicate significant differences ($p<0.05$)

CONCLUSION

Mass transfer during osmotic dehydration and characteristics of tomatoes was influenced by the osmotic agent types and their concentration. The 50% maltose was recommended for the frozen tomatoes, compared to sucrose and sorbitol, because of their positive effect on WL/SG, color, lycopene retention, melting temperature (linking to unfrozen liquid level) and good product quality.

ACKNOWLEDGMENT

Authors acknowledge the financial support received from Mahasarakham University, Thailand.

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