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Full Length Research Paper

Partial removal of water from red pepper by immersion in an osmotic solution before drying

İnanç A. Levent[1]* and Ak Ferit[2]

[1]Department of Food Engineering, Faculty of Agriculture, KSU, Kahramanmaraş, Turkey.
[2]Tunceli Vocational School, Tunceli, Turkey.

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Red pepper is dried for use as a spice. When using solar energy to dry it, there are no energy costs but using other energy sources such as fuel or electricity, the production cost of red pepper spice increase. Due to the fact that energy is becoming expensive globally, it can be envisaged that osmotic dehydration gains more popularity as a pre-processing dehydration step. In this study, red pepper samples were cut into square and immersed in the osmotic solutions prepared at three different concentrations, a defined ratio (sample/solution; g/ml) and several temperatures during osmotic dehydration process time. Water activity, color, solid content, water loss and solid gain of samples were determined during osmotic dehydration process taking place in solutions at different concentration, temperature and time. Statistically, all dependent variables have effect on osmotic dehydration. 60 min of the process was found as the critical point for water loss-solid gain relation. The effect of concentration was significant on water activity of sample. Water activities of samples whose initials were greater than 0.90 reduced below the level of 0.8 at the end of dehydration time, with the exception of a few samples; visible color values were influenced by the process.

Key words: Red pepper, sea salt, water activity color, osmotic dehydration.

INTRODUCTION

Red pepper (*Capsicum annuum* L.) has an important commercial value in the global food industry based on its aromatic, coloring and flavoring properties (Vega-Galvez et al., 2008). Red pepper fruits are used extensively in the food processing industry to a wide range of products such as sausages and meat products as well as for cheeses, butters, salad dressings, condiment mixtures, gelatin desserts and processed foods due to the extractable colors (Govindarajan, 1986), and also it is an indispensable spice used as basic ingredient in a great variety of cuisines all over the world. Capsicum species are employed whole or ground and alone or in combination with other flavoring agents, primarily in the pickles, stewed or barbequed (Ravishankar et al., 2003). Pepper, specifically *C. annuum* is a general name for plants (Luning et al., 1995). The terminology is quite confusing; therefore, pepper chili, chile, chilli, aji, paprika (Csilléry, 2006) and also red pepper. Red pepper is dried for use as a spice. If using solar energy for drying it, there are no energy costs but using other energy sources such as fuel or electricity, the production costs of red pepper spice increase.

In recent years, some pre-treatments including osmotic dehydration, blanching, and microwave have been used for improving the quality of fruit products and reducing energy consumption (Sowti et al., 2002). Osmotic dehydration is used to reduce the water content of the food from 30 to 70% (Lenart and Lewicki, 1988) as an upstream step or the dehydration of food before they are subjected to further processing such as freezing, freezing drying, vacuum drying and air drying (Araujo and Murr, 2002). However, osmotic dehydration will usually not lead to sufficiently low moisture content for the product to be considered shelf-stable (Rahman and Lamb, 1991). The main principles of dehydration of food products by osmosis is water outflow from the product to the solution, solute transfer from the solution to the product and

*Corresponding author. E-mail: linanc@ksu.edu.tr. Tel: +90 344 2191577. Fax: +90 344 2191526.

leaching out of product solutes to the solution. A combination of osmosis, diffusion, flux interactions and shrinkage yields dehydration (Lerici et al., 1985; Quintero-Ramos et al., 1993; Collignan and Raoult-Wack, 1994; Banu et al., 2002). The use of the osmotic dehydration process in the food industry has several advantages: Quality improvement in terms of color, flavor and texture, energy efficiency, packaging and distribution cost reduction, no chemical pretreatment, providing required product stability and retention of nutrients during storage (Rahman and Perera, 1999; Sablani et al., 2002; El-Aouar et al., 2006). This method enables the storage of the product for longer periods, preserves flavour and nutritional characteristics and prevents microbial damage (Segu et al., 2006). The most frequently used dehydrating agents are salts, sugars and corn syrups. Salts are used mainly for vegetables while sugars and corn syrups are used for fruits (Marani et al., 2007).

The influences of concentration and composition of osmotic solution, temperature, immersion time, pretreatments, agitation, nature of food and its geometry, and solution to sample ratio on the process have been studied extensively (Rastogi and Raghavarao, 1997; Kaymak-Ertekin and Sultanoglu, 2000; Matusek and Meresz, 2002; Singh and Gupta, 2007; Kumar et al., 2007; Singh et al., 2008). Water activity (a_w) is the most important factor that affects the stability of dehydrated and dry products during storage. It is determinant for microbial growth and can be associated with most degradation reactions of a chemical, enzymatic and physical nature (Maltini et al., 2003). Knowledge about a_w levels at which microbial growth stops is essential for food preservation purposes. The lowest limit for growth in foods or any other item is 0.6, but most bacteria can be inhibited at a_w of 0.8. To stop yeast and moulds growth, a_w must be as low as 0.75 to 0.7. Control of a_w helps to maintain proper product structure, texture, stability, density and rehydration properties. a_w influences non-enzymatic browning, lipid oxidation, vitamins degradation, enzymatic reactions and protein denaturation (Warczok, 2005). In the paprika pepper varieties (*C. annuum* L.) color can be considered as the main quality factor, since it determines its commercial value (Ricardo et al., 1998). It is well established that physical appearance and presentation of certain foods contribute greatly to a prospective purchaser's sensory response and play a prominent role in final selection and consumption. Out of all the sensory properties of a foodstuff, color, possibly more than any other factor significantly influences customer acceptance because color affects overall judgment and is seen as synonymous with quality, safety and value (Jose´ et al., 1999). Due to the fact that energy is becoming expensive globally, it can be envisaged that osmotic dehydration gains more popularity as a pre-processing dehydration step in the future (Rastogi et al., 2002). During production of red pepper, there is a critical time due to the storage stage of fresh peppers harvested before drying process.

The aim of this work was to evaluate the influence of the osmotic dehydration prior to drying on the moisture content, color and water activity of Maraş red pepper.

MATERIALS AND METHODS

Fresh whole Maraş red peppers (*C. annuum* L.) of variety Sena were directly collected by paying attention that all of the samples could be the same in shape, color, quality and moisture content from a field in Kahramanmaraş, 2008 season, it was determined that the peppers had 16 g weight and 1.5 mm thickness, approximately and were stored at +4°C and relative humidity (RH > 95%) until using them in the experiment. Table salt (NaCl) purchased from Riedel-de Haẻn, Seelze/Germany and Sea salt harvested in France coast obtained from Kartal Birlik Tuz, İstanbul/Turkey were used as osmotic reagents. The main differences between the two salts are the following according to the firm analysis report. Although sea salt (purity 99.0%; weight basis) contains 0.03% Fe, 0.5% Mg and 0.4% Ca and table salt (purity 99.9%) contains none of these elements.

Stalk and seed coat and fused carpels were separated from it after cleaning the pepper. The pepper was cut into square of 10 x 10 mm^2 by using a knife. The osmotic solutions were prepared at three different concentrations (20, 30% and saturated; g/L). The peppers were immersed into these solutions at a ratio of 1:20 sample/solution (g/ml) by selected three different temperatures (25, 35 and 45ºC). No mechanical agitation was applied to solutions to stir. The samples were withdrawn at 30, 60, 90, 120 and 180 min with their surface gently blotted with tissue paper.

Analysis and measurement

Water activity, color, solid content, water loss and solid gain of samples were determined during osmotic dehydration process in solutions at different concentration, temperature and time. Water content was determined by drying at 60°C in an air oven until constant weight according to the method 934.06 (AOAC, 1990). Novasina AW LAB Set H was used to determine a_w of samples and Konica Minolta CR-100 (Color Reader) for visible color L, a and b values. Water loss (W_L), solids gain (S_G) and salt uptake measurements were calculated from the following equations (Özdemir et al., 2008):

$$W_L = \frac{M_{w\ initial} - (M_{final} - M_{s\ final})}{M_{initial}} x100 \quad \text{and} \quad S_G = \frac{M_{s\ final} - M_{s\ initial}}{M_{initial}} x100$$

where

W_L = water loss; %

S_G = solid gain; %

$M_{w\ initial}$ = initial water content before osmotic dehydration (OD); g

M_{final} = the final mass of sample after OD at any time (t); g

$M_{initial}$ = the initial mass of sample; g

$M_{s\ final}$ = final solid content at t; g

$M_{s\ initial}$ = initial solid content; g

Statistical analysis

The significance of the effect of various process parameters on osmotic dehydration was evaluated by the program of SPSS

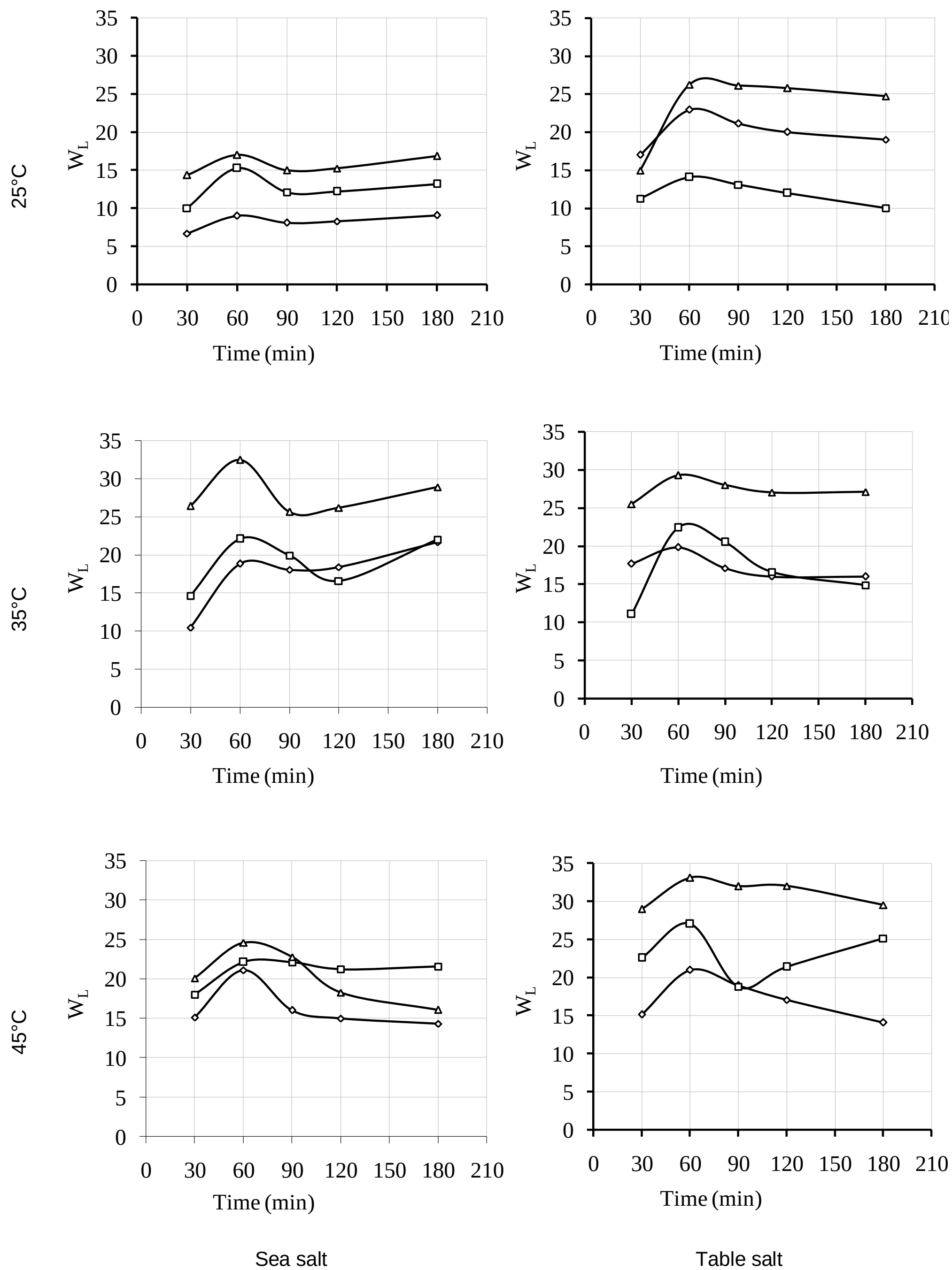

Figure 1. Water losses of samples during osmotic dehydration processes in salt solutions. ◊: 20% salt solution (g/ml), □: 30% salt solution, ∆: saturated solution and W_L: water loss (%).

Statistical 17.0 (2008). Factorial design model was fitted to the experimental data of each dependent variable.

RESULTS AND DISCUSSION

Water losses and solid gain

The changes of W_L and S_G during osmotic dehydration process are presented in Figures 1 and 2. Both irregularly increased with increasing processing time. W_L values varied between the ranges of 9 to 30% at the end of 180 min processes. W_L of the sample immersed in sea salt solution at 35°C and at saturated concentration was found higher than other sea salt solutions. And among samples exposed to OD in table salt solutions, the best W_L was observed in the saturated solutions at 45°C. S_G of samples in sea salt solutions increased between 8 to 20%, the maximum S_G was determined in saturated sea

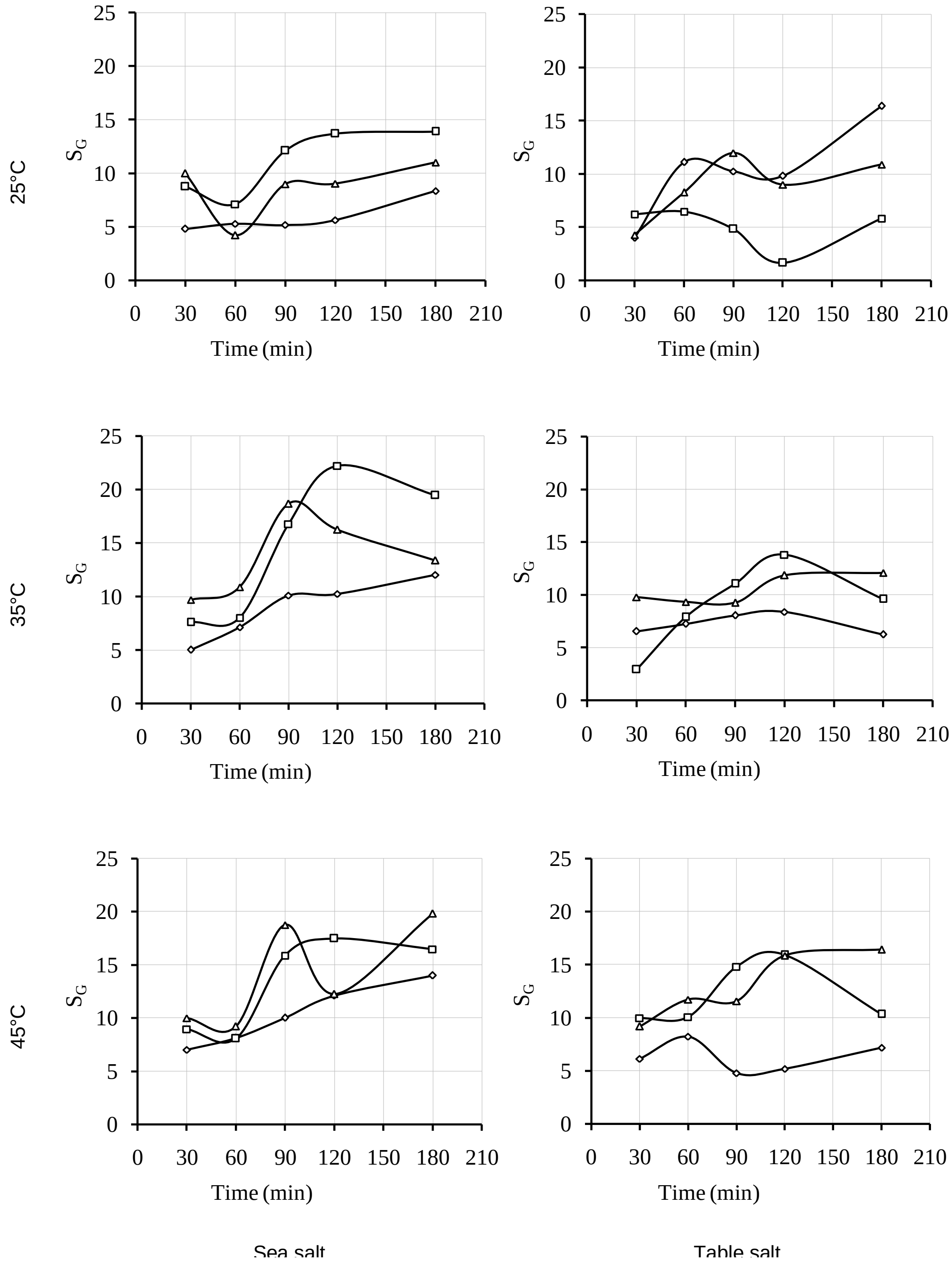

Figure 2. Solid gains of samples during osmotic dehydration processes in salt solutions. ◊: 20% salt solution (g/ml), □: 30% salt solution, Δ: saturated solution and S_G: solid gain (%).

salt solution at 45°C and for S_G of samples in table salt solutions, the increases were found between 6 to 17%, the saturated table salt solution at 45°C gained maximum solid to the red pepper sample. The regression analysis of the experimental data was carried out to observe the significance of the effect of the process variables (concentration, salt type, temperature and time) on W_L and solute gain during osmotic dehydration, and also interactions of each variable with another variable was statistically evaluated for relative effect. The results of analysis of variance (ANOVA) of the experimental data are summarized in Table 1.

The effects of all variables were significant on water loss and exception salt type; on S_G at 1% level of significance ($p < 0.01$). The effects salt type-time, temperature-time and salt type-temperature-time

Table 1. The summary of analysis of variance (ANOVA).

Variable and their interaction	Significance at p level		
	W_L	S_G	Ratio (W_L/S_G) at 60 min
c	< 0.01	< 0.01	< 0.01
s	< 0.01	< 0.05	> 0.05
T	< 0.01	< 0.01	> 0.05
t	< 0.01	< 0.01	-
s-T	< 0.05	> 0.05	> 0.05
s-t	> 0.05	> 0.05	-
T-t	> 0.05	> 0.05	-
s-T-t	> 0.05	> 0.05	-

c: concentration, s: salt type, T: temperature, t: time, W_L: water loss and S_G: solid gain.

Table 2. The results of Tukey tests applied to the experimental data after the ANOVA analysis

	concentration (g/ml)			temperature (°C)			time (min.)							salt type	
	20%	30%	sat'd	25	35	45	0	30	60	90	120	150	180	sea	table
W_L (water loss)	b	b	a	b	a	a	c	b	a	ab	ab	ab	ab	b	a
S_G (solid gain)	b	a	a	b	a	a	c	b	b	ab	a	a	a	_	_
effects of variables: a>ab>b>c															

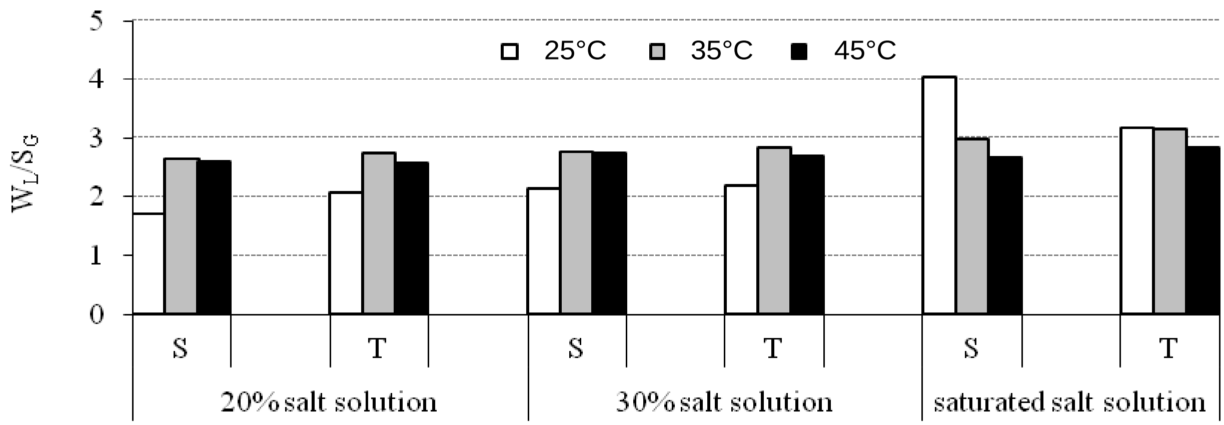

Figure 3. The ratios (W_L/S_G) at 60 min of osmotic dehydration process. S: sea salt, T: table salt, W_L: water loss (%) and S_G: solid gain (%).

interactions were non-significant on W_L and S_G ($p > 0.05$). Tukey test applied to the experimental data after the ANOVA analysis shows that the concentration of 20 and 30% have almost the same effect on W_L during osmotic dehydration and the effect of the saturated was higher than 20% and 30%. The operation temperatures at 35 and 45°C were the most effective than 25°C. The losses in table salt solutions were higher than sea salt type. The maximum W_L was observed at the first 60 min period of dehydration time. Otherwise S_G of sample irregularly rose due to increasing concentration of solution and time. The effects of low temperature and low concentration on S_G were lower than the others (Table 2).

The ratios (W_L/S_G) at 60 min are presented in Figure 3. Only concentration was effective on the ratios at that time ($p < 0.01$), other variables (temperature and salt type) and the interaction of salt-temperature have a non-significant effect at 5% level of significance. However, there are a lot of studies having similar tendency with relation to W_L and S_G during process time for various

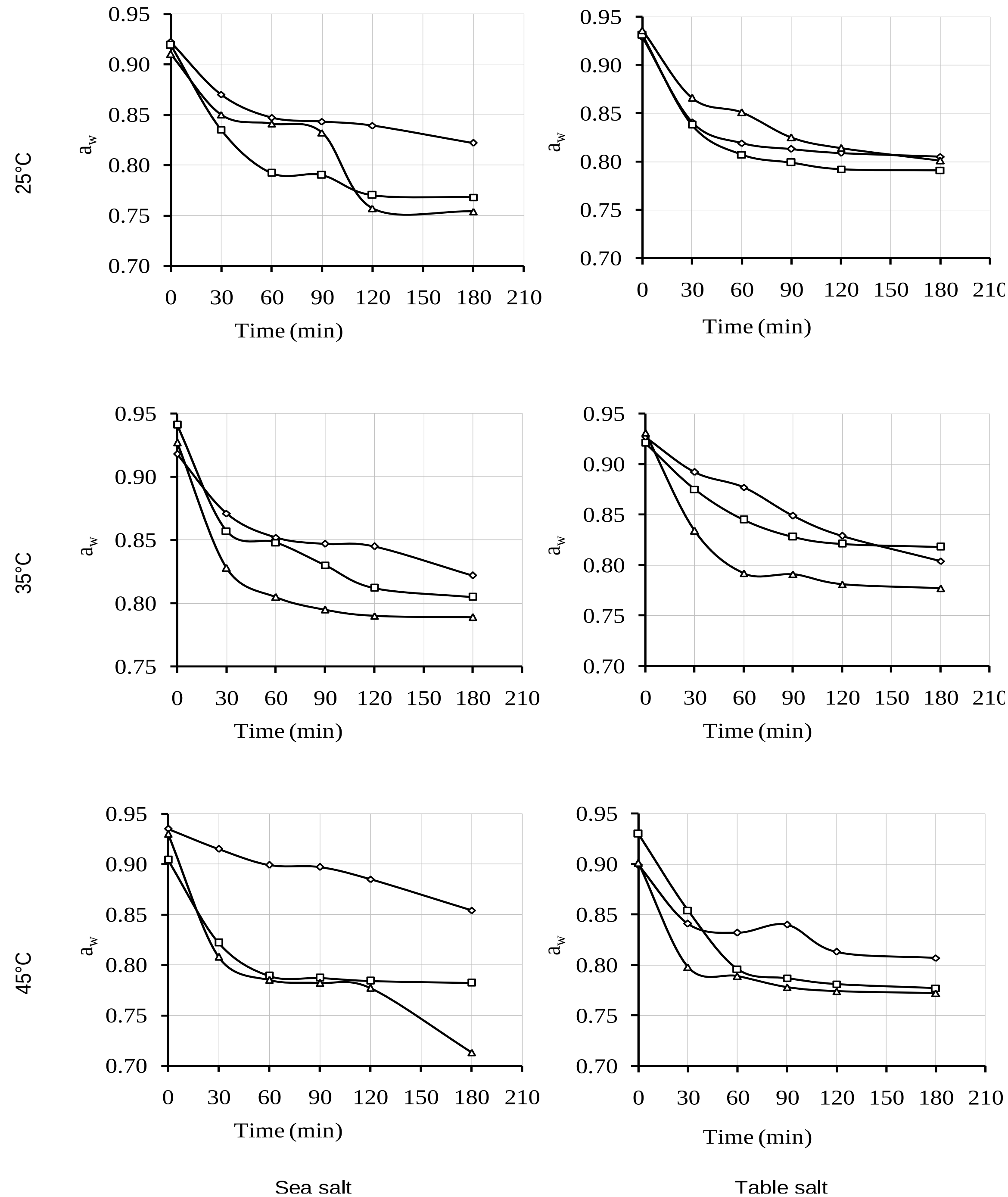

Figure 4. Effect of salt concentration on water activity. ◊: 20% salt solution (g/ml), □: 30% salt solution, Δ: saturated solution and a_W: water activity.

materials using in works, the critical process time for maximum ratio (W_L/S_G) depends on different variable parameters such as solvent, concentration, temperature and also on dimensions and texture structure of the material (Özen et al., 2002; Azoubel et al., 2003, Azoubel and Murr 2004; Ruiz et al., 2005; Sahari et al., 2006; Singh et al., 2007, 2008; Özdemir et al., 2008; Sirousazar et al., 2009; Lertworasirikul and Saetan, 2010; Mercali et al., 2011).

Water activity

Concentration has very significant effect on a_w of sample ($p < 0.01$). Increasing the concentration of osmotic solution and time, a_w is reduced (Figure 4). Salt type, temperature and their interactions have not affected a_w statistically ($p > 0.05$). It was found that the initial a_w values of samples were greater than 0.90. At the end of

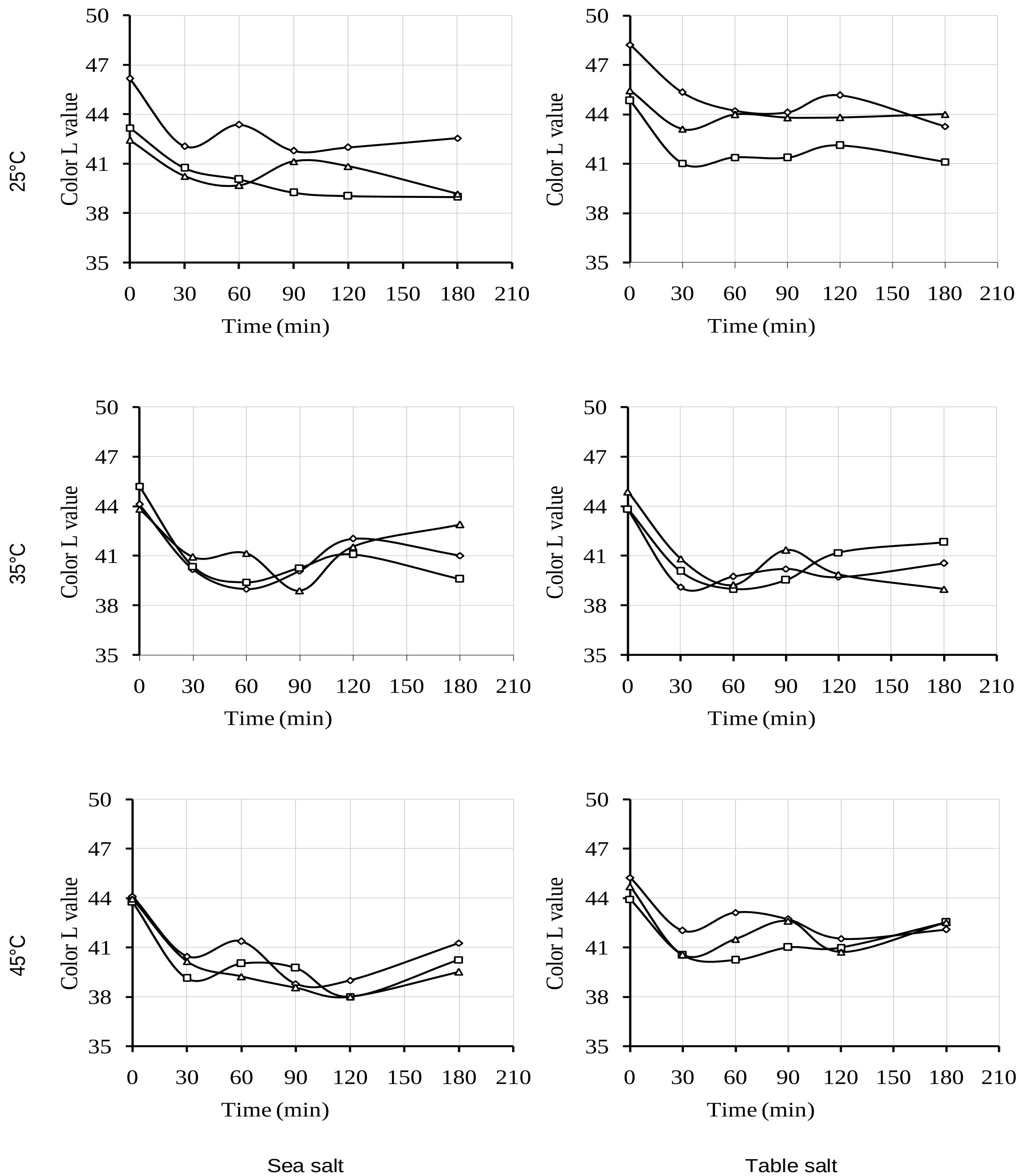

Figure 5. The change of color L value during osmotic dehydration in the salt solution. ◊: 20% salt solution (g/ml), □: 30% salt solution and Δ: saturated solution.

all the dehydration processes time, a_w values reduced below the level of 0.8, exception of a few sample. It was observed that the decreases of a_w at the first 60 min period were maximum. After that time, the a_w of all samples slowly reduced up to the end of the operation times. These data are similar to those reported for other fruit and vegetables such as potato, apples, banana, carrot, etc (Lenart and Flink, 1984; Torregiani, 1993; Özen et al., 2002).

Color measurement

Color is the most important parameter for the acceptability of the product. The color of samples was measured in terms of L, a and b values. The changes in the values of L, a and b was observed as shown in Figures 5, 6 and 7. Concentration, salt type, temperature, time and interaction of salt type-temperature have significant effects on color L values ($p < 0.01$). Effect of

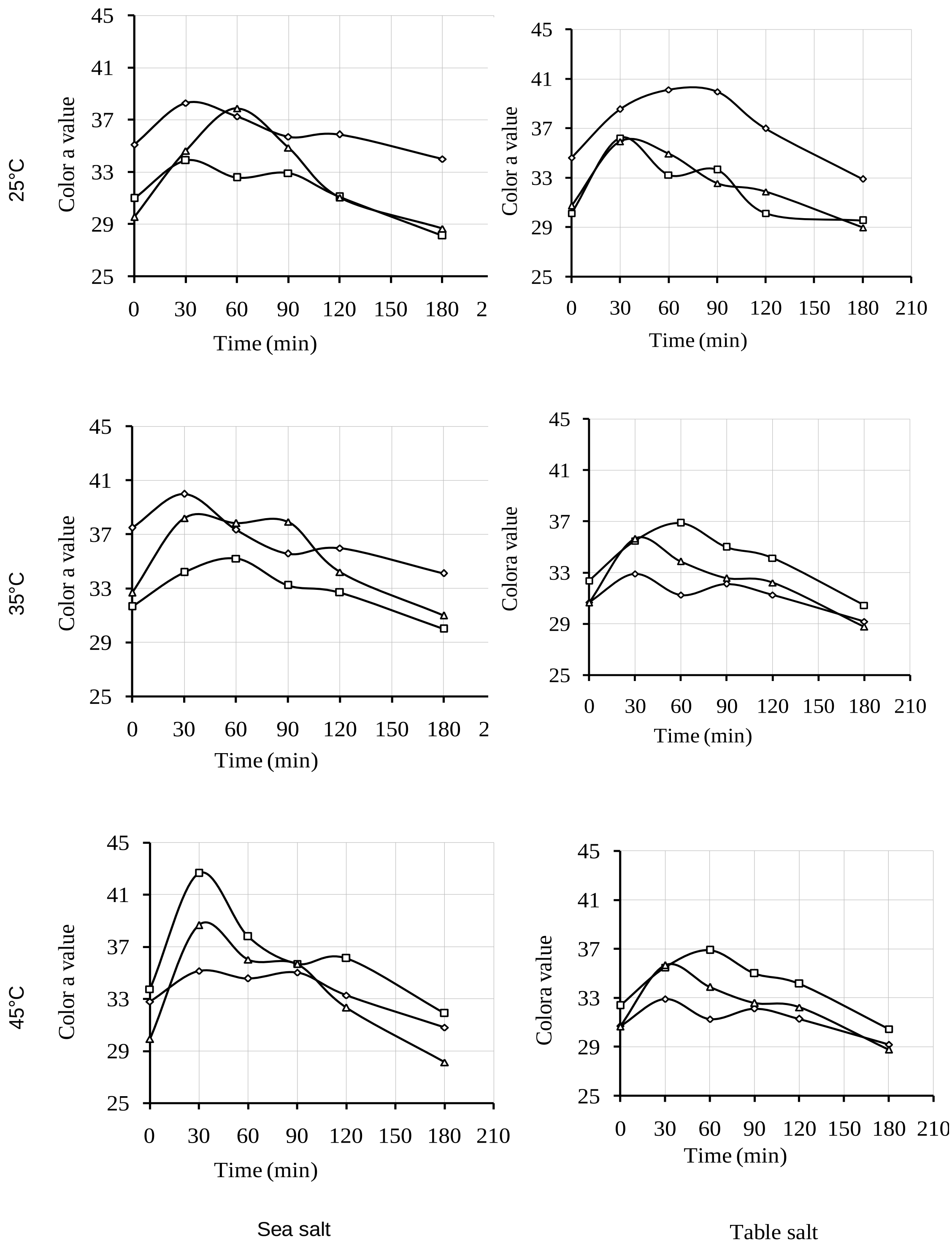

Figure 6. The change of color a value during osmotic dehydration in the salt solution. ◊: 20% salt solution (g/ml), □: 30% salt solution and Δ: saturated solution.

sea salt on color L values is less than table salt. Concentration of 20% and temperature of 25°C have less effect on L value than others. The decreases in the first30 min period during process were found very important compared to other times. Only concentration and time was effective on color value ($p < 0.01$). The other variables and the interactions have no effect on it ($p > 0.05$), but all variables (concentration, salt type, temperature and time) and interaction of salt-temperature have effect on color b value ($p < 0.01$). Color a and b values

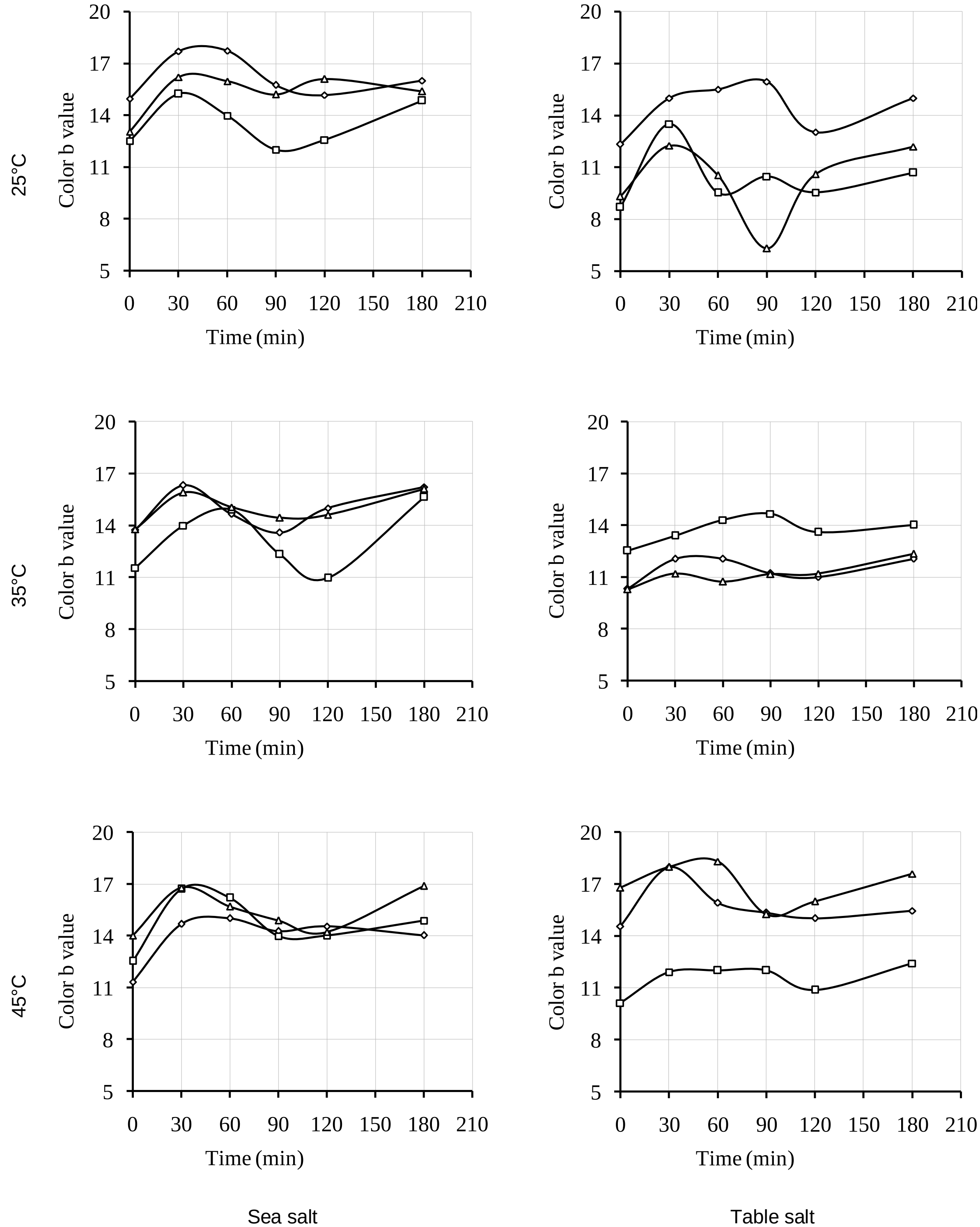

Figure 7. The change of color b value during osmotic dehydration in the salt solution. ◊: 20% salt solution (g/ml), □: 30% salt solution and Δ: saturated solution.

reduced at increasing dehydration time. Chua et al. (2004) explained the decreases in color a and b values as the larger amount of salt gained by the samples leading to significant surface whitening. The values of the color parameters taken could be attributed to the salt layer rather than the actual product color. But Chenlo et al. (2006) reported that osmotic dehydration did not develop significant changes on color working at 25°C regarding the average values of color coordinates for fresh Padrón peppers whereas Singh et al. (2007) reported that all the process parameters had bearing effect on color.

Conclusion

The results showed that the independent process parameters (salt type, concentration, temperature and time) have effects on the osmotic dehydration process. W_L and S_G increased during osmotic dehydration process time but the highest increase in W_L was observed at 60 min of process. This time had been selected as critical point for estimation of relation of maximum W_L to minimum S_G and the ratio of W_L : SG was investigated. The best osmotic dehydration process was found in the process taken place in saturated sea salt solution at temperature of 25°C but overall, table salt has effect than sea salt at all temperatures. Sea salt can be used for osmotic dehydration process because of the cost. a_w is mainly a quality parameter being related with growing microorganism. It was effectively reduced below level of 0.8. Visible color values changed during the process especially color L. This visible surface defect can disappear at the end of the production of red pepper spice. As a result of pre-treatments, osmotic dehydration can be used for improving the quality of red pepper product. In further works, most effective osmotic agents would be investigated for osmotic dehydration process of red pepper.

REFERENCES

AOAC (1990). Official methods of analysis. Association of Official Analytical Chemists, Washington.

Araujo EAF, Murr FEX (2002). Optimization of osmotic dehydration of nectarine (prunus persica) using response surface methodology. Drying' 2002-Proceedings of the 13th International Drying Symposium (IDS' 2002) Beijing, China, 27-30 August' 2002, vol. B, p. 1000.

Azoubel PM, Murr FEX (2004). Mass transfer kinetics of osmotic dehydration of cherry tomato. J. Food Eng. 61: 291-295.

Azoubel PM, Tonon RV, Murr FEX (2003). Effect of osmotic dehydration in sucrose solution in the drying kinetics of cashew apple (*Anacardium occidentale* L.). Drying'2002- Proceedings of The 13th International Drying Symposium (IDS'2002), Beijing, China, 27-30 August' 2002, Vol. B; p. 929.

Chenlo F, Chaguri F, Santos F, Moreira R (2006). Osmotic dehydration/impregnation kinetics of padrón pepper (*Capsicum annuum L. Longum*) with sodium chloride solutions: process modelling and colour analysis. J. Food Sci. Technol. Int. 12: 221.

Chua KJ, Chou SK, Mujumdar AS, Ho JC, Hon CK (2004). Radient-convective drying of osmotic treated agro-products: effect of drying kinetics and product quality. J. Food Control, 15: 145-158.

Collignan A, Raoult-Wack AL (1994). Dewatering and salting of cod by immersion in concentrated sugar/salt solutions. Lebensmittel-Wissenschaft und-Technologie, 27: 259-264.

Csilléry G. (1986). Pepper taxonomy and the botanical description of the species. Acta Agron Govindarajan vs. Capsicum-production, technology, chemistry and quality. III. Chemistry of the color, aroma and pungency stimuli. J. Critical Reviews , Food Sci. Nutr. 4: 245–355.

El-Aouar A, Moreira AM, Barbosa JL, Murr FEX (2006). Influence of the osmotic agent on the osmotic dehydration of papaya (*Carica papaya* L.). J. Food Eng. 75: 267–274.

Kaymak-Ertekin F, Sultanoglu M (2000). Modeling of mass transfer during osmotic dehydration of apples. J. Food Eng. 46: 243–250.

Lenart A, Flink JN (1984). Osmotic concentration of potatoes: criteria fort the end point of the osmotic effect. J. Food Technol. 19: 65-89.

Lenart A, Lewicki PP (1988). Osmotic preconcentration of carrot tissue followed by convection drying, Preconcentration and Drying of Food Materials, ed. S. Bruin, Elsevier Science, Amsterdam, pp. 307-308.

Lerici CR, Pinnavaia G, Dalla Rosa M, Bartolucci L (1985). Osmotic dehydration of fruits; influence of osmotic agents on drying behaviour and product quality. J. Food Sci. 50: 1217-1226.

Lertworasirikul SS (2010). Artificial neural network modeling of mass transfer during osmotic dehydration of kaffir lime peel. J. Food Eng. 98(2): 214-223.

Luning PA, Yuksel D, Vuurst-De-Vries R, Roozen JP (1995). Aroma changes in fresh bell peppers (*Capsicum annuum*) after hot-air drying. J. Food Sci. 60(6): 1269–1276.

Marani CM, Agnelli ME, Mascheroni RH (2007). Osmo-frozen fruits: mass transfer and quality evaluation. J. Food Eng. 79: 1122–1130.

Matusek A, Meresz P (2002). Modeling of sugar transfer during osmotic dehydration of carrots. J. Periodica Polytechnica Chem. Eng. 46: 83–92.

Mercali GD, Ferreira-Marczak LD, Tessaro IC, Zapata-Norena CP (2011). Evaluation of water, sucrose and NaCl effective diffusivities during osmotic dehydration of banana (*Musa sapientum*, shum.). J. Food Sci. Technol. 44(1): 82-91.

Özdemir M, Özen BF, Dock L, Floros JD (2008). Optimization of osmotic dehydration of diced green peppers by response surface methodology. Food Sci. Technol. 41: 2044-2050.

Özen BF, Dock LL, Özdemir M, Floros JD. (2002). Processing factors affecting the osmotic dehydration of diced green peppers. J. Food Sci. Technol. 37: 497-502.

Quintero-Ramos A, De La Vega C, Hernandez E, Anzaldua-Morales A (1993). Effect of the conditions on osmotic treatment on the quality of dried apple dices. In Barbosa-Canovas GV and Okos MR (Eds.), Food dehydration New York: Am. Instit. Chem. Eng. pp. 108-113.

Rahman MDS, Lamb J (1991). Air drying behaviour of fresh and osmotically dehydrated pinapple. J. Food Eng. 14: 163-171.

Rahman MDS, Perera CO (1999). Drying and Preservation. In Rahman MS (Editor), Handbook of food preservation New York; Markel Dekker. pp. 173-216.

Rastogi NK, Raghavarao K, Niranjan K, Knorr D (2002). Recent developments in osmotic dehydration: methods to enhance mass transfer. J. Trends Food Sci. Technol. 13: 48–59.

Rastogi NK, Raghavarao KS (1997). Water and solute diffusion coefficients of carrot as a function of temperature and concentration during osmotic dehydration. J. Food Eng. 34: 429-440.

Ravishankar GA, Suresh B, Giridhar P, Rao SR, Johnson TS (2003). Biotechnological studies on *capsicum* for metabolite production and plant improvement. In: DE, Amit Krishna ed. *Capsicum: The genus Capsicum*. Harwood Academic Publishers, UK, pp. 96-128.

Ricardo G, Pardo JE, Navarro F, Varon R (1998). Colour differences in paprika pepper varieties (*capsicum annuum L*) cultivated in a greenhouse and in the open air. J. Sci. Food Agric. 77: 268-272.

Ruiz RY, Caicedo LA, Camacho G, Clavijo LM (2005). Determining the effect of sucrose osmotic solution re-use on the pineapple's osmotic dehydration kinetic. Enpomer, 2nd Mercusor Congress on Chemical Engineering.

Sablani SS, Rahman MS, Al-Saderi DS (2002). Equilibrium distribution data for osmotic drying of apple cubes in sugar-water solution. J. Food Eng. 5: 193-199.

Sahari AM, Souti M, Emam-Jomeh Z (2006). Improving the dehydration of dried peach by osmotic method. J. Food Technol. 4(3): 189-193.

Segu L, Fito PJ, Albors A, Fito P (2006). Mass transfer phenomena during the osmotic dehydration of apple isolated protoplasts (*Malus domestica* var. Fuji). J. Food Eng. 77: 179–187.

Singh B, Gupta AK (2007). Mass transfer kinetics and determination of effective diffusivity during convective dehydration of pre-osmosis carrot cubes. J. Food Eng. 79: 459–470.

Singh B, Kumar A, Gupta AK (2007). Study of mass transfer kinetics

and effective diffusivity during osmotic dehydration of carrot cubes. J. Food Eng. *79*: 471–480.
Singh B, Panesar PS, Nanda P (2008). Optimization of osmotic dehydration process of carrot cubes in sucrose solution. J. Food Process Eng. 31: 1-20.
Singh P, Panesar SP, Nanda V (2007). Rehydration kinetics of un-osmosed and pre-osmosed carrot cubes. World J. Dairy Food Sci. 2(1): 10-17.
Sirousazar M, Mohammadi-Doust A, Achachlouei BA (2009). Mathematical investigation of the effects of slicing on the osmotic dehydration of sphere and cylinder shaped fruits. Czech J. Food Sci. 27(2): 95–101.
Sowti -Khiabani M, Emam-Djomeh Z, Sahari MA (2002). Improving the quality of sun-dried peaches by osmotic dehydration pre-treatment. Drying' 2002-Proceedings of the 13th International Drying Symposium (IDS' 2002) Beijing, China, 27-30 August' 2002, vol. B, pp. 952 The genus Capsicum. London: CRC Press; 2003. p. 100.
Torreggiani D (1993). Osmotic dehydration in fruit and vegetable processing. J. Food Res. Int. 26: 59-68.
Vega-Galvez A, Lemus-Mondaca R, Bilbao-Sainz C, Fito P, Andres A (2008). Effect of air drying temperature on the quality of rehydrated dried red bell pepper (var. *Lamuyo*). J. Food Eng. 85: 42–50.
Warczok J (2005). Concentration of osmotic dehydration solutions using membrane separation processes. Memoria presentada por Justyna Warczok Para optar al Título de doctor en Ingeniería química Tarragona, Universitat Rovira i Virgili Escola Tècnica Superior d 'Enginyeria Química Departament d 'Enginyeria Química.