International Food Research Journal 18(4): 1223-1230 (2011)

Osmo-dehydration pretreatment for drying of pumpkin slice

[*]Lee, J. S. and Lim, L. S.

School of Food Science and Nutrition, Universiti Malaysia Sabah,
Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia

Abstract: This study was designed to elucidate the effects of osmotic dehydration of pumpkin slice prior to hot-air drying. Response Surface Methodology (RSM) with Central Composite Design was used to investigate the influence of three variables, namely sucrose concentration (30-60˚Brix), immersion temperature (35-65˚C) and immersion time (90-120 min). These factors increased the solid gains and decreased the water activity (a_w) of the sample; while the temperature and sucrose solution concentration increased the water loss ($p<0.05$). These changes affected the L^* and b^* values of the final product ($p<0.05$). The process temperature also affected the sensorial properties by increasing the sweetness, dryness, hardness and overall acceptance of the dried pumpkin slice ($p<0.05$). However, increasing temperature caused the deterioration of colour and aroma. Longer immersion time was found to increase shrinkage, sweetness and overall acceptability of the final product. The optimum osmotic dehydration pretreatment was predicted as immersion using 57.8˚Brix sucrose solution at 58.3˚C for 146.7 minutes.

Keywords: Pumpkin, osmotic dehydration, Response Surface Methodology, sensory evaluation

Introduction

Osmotic dehydration (OD) is a technique that involves product immersion in a hypertonic aqueous solution leading to loss of water through the cell membranes of the product and subsequent flow along the inter-cellular space before diffusing into the solution (Sereno *et al*., 2001). The removal of water out of the tissue is completed by a counter-current diffusion of the osmotic agent from the solution toward the tissue. These two simultaneous transports bring about depressing effect on the water activity (a_w) of the samples (Prothon and Ahrné, 2004). As a result, osmotic dehydration can be applied either as an autonomous process or as a pre-treatment in alternative process, such as freezing, freeze drying, vacuum drying and air drying. In recent years, osmotic dehydration has received considerable attention due to the low temperature employ in the process that improves the final product quality and reduces energy consumption.

Besides reducing the drying time, osmotic dehydration is used to treat fresh produce before further processing to improve sensory, functional and even nutritional properties. It has been proven to improve the texture characteristics of thawed fruits and vegetables (Chiralt *et al.*, 2001; Talens *et al.*, 2002), decrease structural collapse (Simal *et al*., 1997; Del *et al.*, 1998), and retain natural colour as well as volatile compounds during subsequent drying (Pokharkar *et al*., 1997). Water content reduction and sugar gain during osmotic dehydration have been observed to have some cryoprotectant effects on colour and texture in several frozen fruits (Chiralt *et al*., 2001). By using trehalose in osmotic solution, Aktas *et al.* (2007) observed less shrinkage, better colour properties and better cell reconstruction properties for dried carrot and potato. Osmoactive substances such as sucrose and sodium chloride could preserve and even increase the lycopene and β-carotene content of cherry tomato by affecting the integrity of the cellular matrix (Heredia *et al*., 2009). The benefits offer has directed the attention of studies on osmo-dehyration of a wide variety of fruits and vegetables such as mango (Torres *et al*., 2006), pear (Park *et al*., 2002), cantaloupe (Corzo and Gomez, 2004), apple and pineapple (Sujata and Das, 2005; Lombard *et al*., 2008), cauliflower (Vijayanand *et al*., 1995), cherry tomato (Azoubel and Murr, 2004), mushroom (Torringa *et al*., 2001) and so forth. As an important food and also a medicinal therapeutic, pumpkin also received attention as subject of research by several investigators.

Pumpkin covers a wide number of species of the family *Cucurbitaceae*, most of them with actual or potential economic value. Pumpkins are good sources of carotenoids, and some varieties are rich in provitamins A, mainly α-carotene and β-carotene (Marek *et al*., 2008). Caretenoids are among the phytochemical components believed to reduce the risk of developing some degenerative diseases, and are responsible for the attractive colour of many fruits and vegetables. Pumpkin fruit is also a valuable source of other vitamins, e.g., B6, K, thiamine, and riboflavin, as well as minerals, e.g., potassium, phosphorus, magnesium, iron and selenium (USDA National Nutrient Database, 2004).

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*Corresponding author.
Email: *jslee@ums.edu.my*
Tel: +6088 320256; Fax: +6088 320259

The drying of pumpkin (with and without OD) has been investigated by several authors. Garcia *et al*. (2007) applied osmotic drying prior to convective drying; Arévalo-Pinedo and Murr (2007) studied combination of osmotic dehydration and vacuum drying; Kumar *et al*. (2001) employed initial partial freeze-drying followed by terminal hot air-drying; whilst Alibas (2007) reported microwave dehydation of pumpkin. Shafafi Zenoozian *et al*. (2008) investigated the effect of OD on hot-air drying kinetics of pumpkin in order to identify the best model for describing the drying process. Narwirska *et al*. (2009) compared a few drying methods (convective, vacuum-microwave, vacuum and freeze drying) on the drying kinetics and quality of 12 pumpkin cultivars. They reported vaccum-microwave drying produced pumpkin slice with more attractive colour and more effective than convective method. From literature, OD of pumpkin has been studied in either salt solution (Mayor *et al*., 2006) or sugar solutions (Pan *et al*., 2003; Gracia *et al*., 2007; Kowalska *et al*., 2008). In general, a significant reduction in the thermal drying time is obtained for the impregnated materials in comparison to the fresh material. The use of biological active components in osmotic solution, like vitamins and minerals such as Ca^{2+} and Zn^{2+} allows transfer of the substances to the cell tissue that enhance the health benefits of the impregnated materials. de Escalada Pla *et al.* (2009) reported pumpkin (*Cucurbita moschata* Duchesne ex Poiret) mesocarp tissues is suitable to be a fiber-rich food matrix for iron supply after soaking in Fe^{2+} rich osmotic solution. *In vitro* digetion study found that all iron present was biologically avaibale.

Osmotic dehydration of pumpkin can be a useful technique to preserve and obtain new processed products of interest to the consumer. Furthermore, pumpkin is considered as a good model of a natural fruit tissue for this type of studies due to its homogeneity and extended shelf life (Mayor *et al*., 2006). This study was aimed to produce a novel shelf stable high quality dried pumpkin slice using combination of OD and conventional hot-air drying. The OD pretreatment process condition was optimized in order to produce end product with the best sensorial quality.

Materials and Methods

Fresh material

Pumpkins (*Cucurbita moschata*) were purchased in a local market selected on the basis of a similar ripening degree, e.g. index 5 of Standard and Grade Specification for pumpkin by Federal Agricultural Marketing Authority (FAMA), Malaysia. Whole pumpkins without any damage were selected with average height of 19 ± 1 cm, diameter of 24 ± 1 cm and weight of 3 ± 0.3 kg to maximize the uniformity of the raw material. The moisture content and soluble solid content of pumpkins range between 95 – 97% (wet basis) and 2 – 4^{o}Brix respectively (Mayor *et al*., 2008). Commercial sucrose was purchased from local market.

Experimental design

A Central Composite Design (CCD) consisting of three factors at three levels was employed to prepare dried pumpkin slice. The independent variables were solution temperature (35, 50 and 65^{o}C), immersion time (90, 150 and 210 min) and sucrose concentration (30, 45 and 60% w/w). Each independent variable was codedat three levels between -1 and +1 and a total of 20 experimental run was generated (Table 1). The critical ranges of selected parameters were determined by preliminary experiments based on the literature review. Dried pumpkin slice without OD pretreatment was used as control sample for this study.

Table 1. Experimental runs generated by Central Composite Design (CCD) for osmotic dehydration of pumpkin slice

Run	Solution Temperature (^{o}C)		Immersion Time (min)		Sucrose Concentration (% w/w)	
	Actual value	Coded value	Actual value	Coded value	Actual value	Coded value
1	50.0	0	250.8	+1.68	45.0	0
2	35.0	-1	90.0	-1	30.0	-1
3	65.0	+1	210.0	+1	60.0	+1
4	75.2	+2	150.0	0	45.0	0
5	35.0	-1	210.0	+1	30.0	-1
6	50.0	0	150.0	0	45.0	0
7	35.0	-1	90.0	-1	60.0	+1
8	65.0	+1	90.0	-1	30.0	-1
9	50.0	0	150.0	0	45.0	0
10	50.0	0	150.0	0	45.0	0
11	50.0	0	150.0	0	45.0	0
12	35.0	-1	210.0	+1	60.0	+1
13	65.0	+1	210.0	+1	30.0	-1
14	50.0	0	150.0	0	45.0	0
15	65.0	+1	90.0	-1	60.0	+1
16	24.8	-1.68	150.0	0	45.0	0
17	50.0	0	150.0	0	19.8	-1.68
18	50.0	0	150.0	0	70.2	+1.68
19	50.0	0	49.2	-1.68	45.0	0
20	50.0	0	150.0	0	45.0	0

Sample preparation

Fresh pumpkin was cleaned, peeled and cut with knife into rectangular slabs (60 mm length x 15 mm width x 10 mm thick). The zone near the peel (<10 mm) was removed because of its different texture. The spongy portion in the core and seeds were also discarded.

Osmotic solution was prepared into specific concentration using commercial sucrose and distilled water. The concentration of osmotic solution was monitored using a refractometer and held in a waterbath (DAIHAN Scientific, WB-11, Korea) to achieve required solution temperature. Samples were dipped in sucrose solution of a specified concentration for an assigned time. The pumkin:solution ratio was fixed at 1:5 (w/w) throughout the experiment. The osmotic medium and content was agitated manually at every 30 min interval to avoid localize dilution of sucrose solution. After osmotic dehydration treatment, the samples were withdrawn from the solution and blotted with tissue paper to remove adhering sugar solution. After that, the osmodehydrated pumpkin was dried in a hot-air dryer (Protech, FDD-720, Malaysia) at 60°C until reaching 15% final moisture content.

Determination of moisture, a_w and soluble solid

The moisture content in samples was determined gravimetrically at 105°C. The a_w was measured with a water activity meter (Rotronic, HygroLab 3, Switzerland). Soluble solid content per cent in the sample liquid phase was determined by measuring the refraction index in a refractometer (Atago, BC-3E, Japan) at room temperature.

Determination of water loss (WL) *and solid gain* (SG)

Osmotic dehydrated samples were blotted with tissue paper and later weighed for determination of *WL* and *SG* as shown by the following equation (Aktas *et al*., 2007):

$$WL = \frac{W_{wo} - W_w}{W_o} \times 100$$

$$SG = \frac{W_s - W_{so}}{W_o} \times 100$$

where, *WL* and *SG* are water loss and solid gain in %, respectively. W_{wo} is the initial water mass, W_w is the mass of water at time t, W_S is the solid mass at time t, W_{so} is the initial solid mass, and M_o is the initial mass (water + solid) of the fresh pumpkin (prior to osmotic dehydration treatment).

Determination of colour

Colour of pumpkin samples were measured using colourimeter (Konica Minolta, CR-400, Japan). The meter was calibrated using the manufacturer's standard white plate. Tristimulus values of $L^*a^*b^*$ were recorded directly from the colourimeter. L^* represents the lightness, a^* represents redness and b^* represents the yellowness.

Sensory evaluation

Multiple Comparison Test was employed to identify differences between pumpkin slice samples. Due to high number of samples, a Balance Incomplete Block (BIB) Design was used (Cochran and Cox, 1957). The sensory evaluation was designed to measure the differences between dried pumpkin slices treated with various OD processing parameters and without OD (control sample). A total of 35 panelists (20 female and 15 male within the age group of 20 – 35 years) participated in the test. Each panelist compared three samples to the reference on a 7-point scale. Denotations of the scores of the scale were as follows: 1 = very weak in comparison to reference, 2 = weaker than reference, 3 = slightly weaker than reference, 4 = no difference with reference, 5 = slightly stronger than reference, 6 = stronger than reference and 7 = very strong in comparison with reference. The attributes evaluated included colour, sweetness, surface dryness, aroma, shrinkage, hardness (first bite), and overall acceptability. All samples were labeled with three digit codes and distilled water was served for mouth rinsing. The sensory evaluation sessions were conducted in the sensory laboratory, where panelists were isolated from one another in sensory booths.

Statistical analysis

Response Surface Methodology was used to design experiment, model and optimized selected response variables. The statistical software package (Design-Expert ver 7.0, Stat-Ease Inc., Minneapolis, USA) was used for regression analysis of experimental data and to plot response surface. The generalized second-order polynomial model used in the response surface analysis was as follow:

$$\eta = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} \beta_{ij} x_i x_j$$

where η is the dependent variable (response variable) to be modeled, x_i and x_j are the independent variables (factors), β_0, β_i, β_{ii}, β_{ij} are the regression coefficients for intercept, linear, quadratic, and interaction terms.

Experimental data were fitted to the second-order polynomial model and regression coefficients obtained. The model was simplified by dropping terms which were not statistically significant ($p>0.05$) by analysis of variance (ANOVA). The response surface and contour plots were generated by holding a variable constant in the second-order polynomial model.

Optimization of independent variables for osmotic dehydration of pumpkin slice was determined by superimposing the plots for selected responses. The optimum conditions and the predicted values of the response variables were obtained using the graphical method of the software.

Results and Discussions

Water loss and solid gain

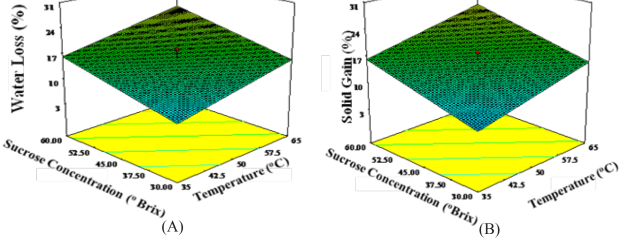
Regression equations describing the effect of osmotic dehydration on the water loss *(WL)* and sucrose gain *(SG)* of pumpkin slices are given in Table 2. Differ from quadratic effect reported by Uddin *et al*. (2004) for osmotic dehydration of carrot using sucrose; results obtained reveal that both responses were affected by three variables studied in a linear manner. It is noted that sucrose concentration and solution temperature exerted more pronounced effect (higher coefficient values). Relatively high correlation coefficients (i.e. R^2) were obtained for both responses indicating good fit of experimental data to the linear equation. No significant interaction effect between the studied variables was detected ($p>0.05$).

Table 2. Estimated regression coefficients of predicted models for water loss (*WL*), solid gain (*SG*) and water activity (a_w) for osmotic dehydration of pumpkin slice

Factor	*WL*	*SG*	a_w
β_0 (Intercept)	16.04	16.11	0.60
β_1 (Solution temperature)	3.29*	3.53***	-0.017***
β_2 (Sucrose concentration)	3.70**	3.88***	-0.020***
β_3 (Immersion time)	2.66*	2.63**	-0.016***
R^2	0.7196	0.7471	0.8845

$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

The effect of changing sucrose concentration and solution temperature on the percentage *WL* and *SG* are shown in Figure 1. Increasing of sucrose concentration, solution temperature and immersion time induced water loss and solid uptake in pumpkin slices ($p<0.05$). During OD chemical changes in food occurred. Transfer of water and osmo-active substance is accompanied by a stream of natural solutes leaking from the tissue into the hypertonic solution. The concentration difference between the sucrose solution and the pumpkin created two simultaneous flows in counter-current through the cell walls, one of water which moves to the solution and the other of sucrose from the solution to the pumpkin. This process is going on to equilibrium of chemical potential between osmo-active solution and the cell sap. As a result, *WL* is always closely associated with *SG* in osmotic dehydration treatment.



(A) (B)

Figure 1. Response surface plot for (A) water loss and (B) solid gain of pumpkin slice during osmotic dehydration

According to Barbosa-Córnvas and Vega Mercado (1996), the migration of solute in osmotic dehydration depends on the selectivity and permeability of the foods, contact time and size of the material. Higher temperatures promote faster water loss through swelling and plasticizing of cell membranes as well as the better water transfer characteristics on the product surface due to lower viscosity of the osmotic medium (Contreras and Smyral, 1981; Lazerides *et al*., 1997). Thus, high temperature would release trapped air from the pumpkin tissue resulting in more effective removal of water by osmotic pressure. In general, higher osmotic solution concentration leads to higher solutes uptake. On the other hand, low osmotic solution concentration implies a lower process driving force and subsequently longer treatment time.

The water activity suppression effect was also observed in this study whereby all three factors affected the a_w of dried pumpkin slice in linear manner (Table 1). Pumpkin slice prepared without OD was reported to be 0.657 ± 0.012, once treated with osmotic solution, the a_w of the sample was able to be kept between 0.558-0.651. This provided better preservation effect as water has a decisive direct influence on the quality and durability of food products through its effect on many physic-chemical and biological changes.

Determination of colour

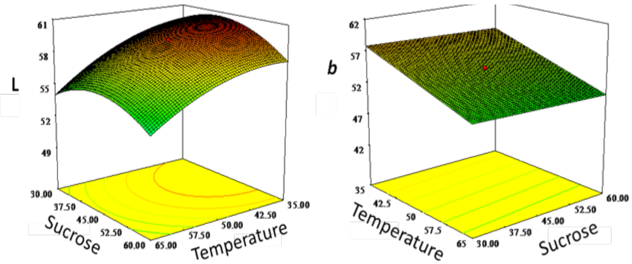
Differences in mass transport and structural changes promoted in the tissue by different process conditions resulted different colour in osmo-dehydrated pumpkin slice. Table 3 shows that only the lightness (L^*) and yellowness (b^*) of the pumpkin slice were affected by the treatment variables ($p<0.05$). Changes in redness (a^*) was independent of the OD treatment. Among the process variables, solution temperature exerted more prominent effect on the colour of the pumpkin slice. L^* was affected by the treatment variables in quadratic manner whereas b^* was affected linearly. An increase of the L^* value was seen as the sucrose concentration was increased from 30°Brix and dropped beyond 45°Brix. Increase of immersion time and temperature reduced the lightness of the sample (Figure 2A and Table 3). As the process progressed under higher temperature and longer immersion period, the shrinkage of the tissue structure would cause increase in sample opacity (Contreras *et al*., 2008) hence lowered the lightness. On the other hand, higher temperature reduced the yellowness of the sample (Figure 2B) resulted from the concentration of pigment present in the cellular tissue due to lower liquid phase available after OD treatment. Heredia *et al.* (2009) reported increase of a^* and b^* with the processing temperature in osmotic dehydration of cherry tomato using sucrose solution.

Several studies reported the existence of a linear

Table 3. Estimated regression coefficients of predicted models for lightness (L^*), redness (a^*), yellowness (b^*) and sensory acceptability of osmotic-dehydrated pumpkin slice

Factor	L^*	a^*	b^*	Overall Acceptability
β_0 (Intercept)	59.25	21.24	54.54	5.20
β_1 (Solution temperature)	-2.42***	-0.53	-3.05***	0.25*
β_2 (Sucrose concentration)	-0.55	0.96	-0.30	0.11
β_3 (Immersion time)	-1.04*	0.80	0.021	0.26*
β_{11}	-1.19**	-	-	-0.13
β_{22}	-1.74***	-	-	-0.33**
β_{33}	-0.82*	-	-	-0.34**
β_{12}	0.39	-	-	0.11
β_{13}	-0.78	-	-	-0.12
β_{23}	0.63	-	-	-0.23
R^2	0.8903	0.2811	0.5605	0.8394

*p<0.05; **p<0.01; ***p<0.001



(A) (B)

Figure 2. Response surface plot for (A) lightness and (B) yellowness of dried pumpkin slice

correlation between a^* and b^* kinetics with carotenoids concentration and suggested the use of colour instead of pigment content measurement for quality control of food products (Ahmed *et al*., 2002; Dutta *et al*., 2006). It is known that carotenoids (β-carotene, α-carotene and lutein) are responsible for the colour of pumpkin (González *et al*., 2001). Non-enzymatic browning reactions took place altogether with oxidation and isomerization of β-carotene during processing (Dutta *et al*., 2006) and degraded the colour of the pumpkin slice. Data obtained evident that OD pretreatment was able to reduce the discolouration of pumpkin slice attributed to hot air drying. Control sample was found darker in colour (L^*= 42.6 ± 3.29; a^*= 8.4 ± 0.49 and b^*= 39.4 ± 2.23) when compared to the pretreated samples. OD treated samples reported L^* and b^* values range between 49.3 – 60.4 and 42.1 – 61.1 respectively.

Sensory evaluation

In line with the results of colour determination, feedback of sensory panelists indicated that the colour of pumpkin slice was affected by the process temperature (p<0.05). As temperature increased from 35°C to 65°C, the colour of the sample became less attractive as compared to the control sample (Figure 3). Meanwhile only immersion time was found to have a positive quadratic effect on the shrinkage of pumpkin slice (p<0.05); whereby the shrinkage of OD treated sample reduced along with increase of immersion time from 90 min, reaching the minimal shrinkage around 120 min and increased thereafter (Figure 3). One of the major adverse effects of hot-air drying of fruit or vegetable is the extensive shrinkage and microstructural changes in the tissue of final product. In general, all OD treated samples were found to experience less shrinkage than control (sensory scores <3.5). The volume occupied by sucrose impregnated in the tissue (Garcia *et al*., 2007) due to OD treatment avoided the structural collapse and hence further shrinkage.

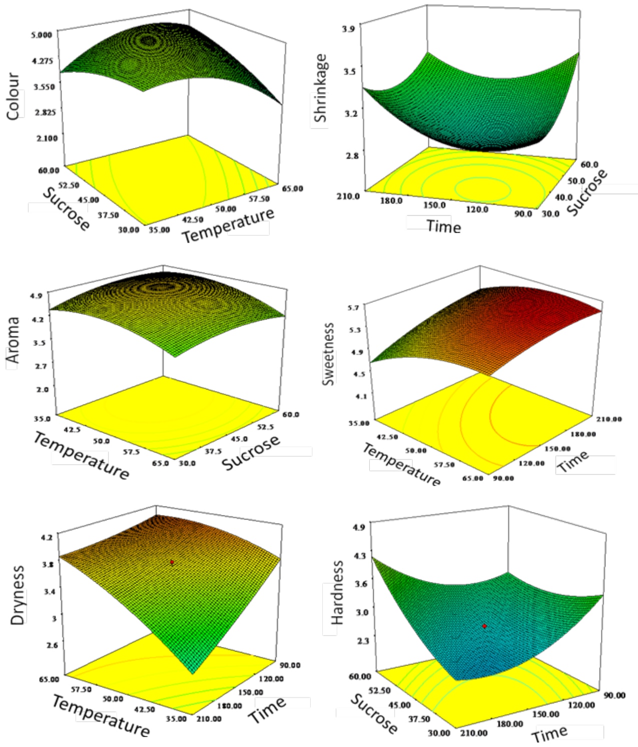


Figure 3. Response surface plot for colour, shrinkage, aroma, sweetness, dryness and hardness of osmotic dehydrated pumpkin slices obtained from sensory evaluation

In addition to the compositional changes provoked by mass transport, different chemical changes have been reported in fruits submitted to osmo-dehydration. The loss of aroma was registered with increase of process temperature (Figure 3). Chiralt and Talens (2005) also reported osmotic treatment induced changes in major characteristic volatiles compounds in strawberry and kiwi, depending on sucrose concentration and vacuum pulse application. OD pretreatment preserved the pumpkin aroma in which all treated samples were rated to have stronger aroma than control (sensory scores >4). Longer immersion time and higher reaction temperature increased the sweetness and dryness of pumpkin slice (p<0.05). In the meantime, the three process variables during osmotic pretreatment induced hardness of the pumpkin slice in quadratic manner (Figure 3). This attribute was also increased by interaction effect between sucrose concentration and immersion time (p<0.05). The entire treated dried pumpkin slice was softer and of better quality than the control sample. During osmosis process, heat treatment given through concentration solution, which loosen the texture and subsequently soften the product to improve the texture (Shukla and Singh, 2007). However, it should be noted that long immersion time using high sucrose concentration may cause excessive sugar uptake and hardening of sample.

The regression equations obtained evident that all three variables influenced the overall acceptability of the final product. Sucrose and immersion time affected the attribute in quadratic manner, while temperature in linear manner (Table 3). Since OD improved all the sensory attributes tested, the overall acceptability of all the treated samples was rated higher than control (score = 4). Figure 4 shows that different process conditions used during OD influenced the sensory properties and acceptability of the final product. Identifying the right combination of process conditions is therefore critical to ensure acceptable dried pumpkin slice.

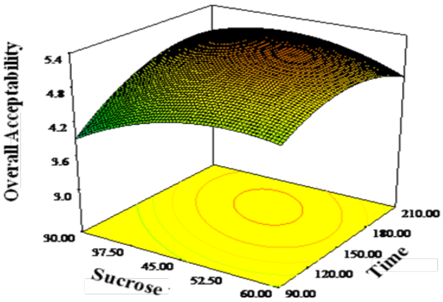


Figure 4. Response surface plot for sensory overall acceptability of osmotic pretreated dried pumpkin slice

Optimization of osmotic dehydration pretreatment

A graphical multi-response optimization technique was adopted to determine the optimum operating conditions for OD pretreatment of pumpkin slice with the expected characteristics. The contour plots for all the responses were superimposed, and regions that best satisfy all the constraints were selected as optimum conditions (Figure 5). The main criterion for constrain optimization was minimum possible a_w; maximum possible L^*, b^* and overvall acceptability; dryness (2-4); shrinkage and hardness (3-4); colour (3-5); aroma (5-6); sweetness and chewiness (5-7). The optimum region covered temperature range at 58-60°C, immersion time for 108-155 min and 59-60°Brix sucrose solution. The optimum osmotic dehydration pretreatment was predicted as immersion using 57.8˚Brix sucrose solution at 58.3˚C for 146.7 min.

However, it should be kept in mind that the optimum condition obtained in this study is valid within the limits of experimental factors used. Therefore, the extrapolation of the responses beyond the experimental range of the independent variables applied in this study may not be valid.

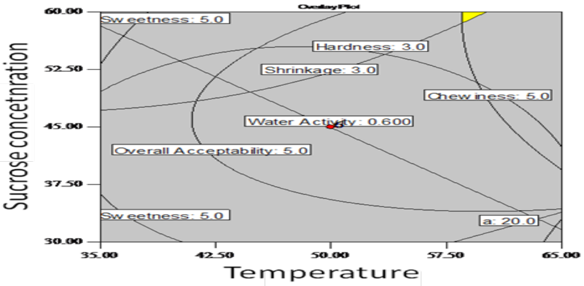


Figure 5. Superimposing contour plots for optimization of osmotic dehydration treatment

Conclusions

It can be concluded from this study that solution temperature and sucrose concentration were the most pronounced factors affecting sucrose gain and water loss of pumpkin slice during osmotic dehydration followed by immersion time. Results obtained evident that osmotic dehydration using sucrose solution was able to improve the quality of hot air drying of pumpkin slice in term of the colour, shrinkage, texture, aroma as well as sensory acceptability. The regression equations obtained in this study were successfully used to predict optimum conditions for the desired sensory and physical properties of dried pumpkin slice.

References

Ahmed, J., Shivhare, U. S. and Sandhu, K. S. 2002. Thermal degradation kinetics of carotenoids and visual colour of papaya puree. Journal of Food Science 67(7): 2692–2695.

Aktas, T., Fujii, S., Kawano, Y. and Yamamoto, S. 2007. Effects of pretreatments of sliced vegetables with trehalose on drying characteristics and quality of dried products. Trans IChemE, Part C, Food and Bioproducts Processing 85 (C3): 178-183.

Alibas, I. 2007. Microwave, air and combined microwave-air-drying parameters of pumpkin slices. LWT – Food Science and Technology 40: 1445–1451.

Arévalo-Pinedo, A. and Murr, F.E.X. 2007. Influence of pre-treatments on the drying kinetics during vacuum drying of carrot and pumpkin. Journal of Food Engineering 80: 152–156.

Azoubel, P.M. and Murr, F.E.X. 2004. Mass transfer kinetics of osmotic dehydration of cherry tomato. Journal of Food Engineering, 61: 291–295.

Barbosa-Cánovas, G.V. and Vega-Mercado, H. 1996. Dehydration of Foods. Boca Raton: International Thomson Publishing, Chapman and Hall.

Chiralt, A. and Talens, P. 2005. Physical and chemical changes induced by osmotic dehydration in plant tissues. Journal of Food Engineering 67: 167-177.

Chiralt, A., Martínez-Navarrete, N. M., Martínez-Monzó, J., Talens, P., Moraga, G. and Ayala, A. 2001. Changes in mechanical properties throughout osmotic processes. Cryoprotectant effect. Journal of Food Engineering 49:129–135.

Cochran, W.G. and Cox, G.M. 1957. Experimental Designs. 2nd Edn. New York: John Wiley and Sons, Inc.

Contreras, C., Martı´n-Esparza, M.E., Chiralt, A. and Martı´nez-Navarrete, N. 2008. Influence of microwave application on convective drying: effects on drying kinetics and optical and mechanical properties of apple and strawberry. Journal of Food Engineering 88(1):55-64.

Contreras, J. E. and Smyral, T. G. 1981. An evaluation of osmotic concentration of apple rings using corn syrup solids solutions. Canadian Institute of Food Science and Technology Journal 14: 310–314.

Corzo, O. and Gomez, E.R. 2004. Optimization of osmotic dehydration of cantaloupe using desired function methodology. Journal of food engineering 64:213-219.

de Dscalada Pla, M.F., Campos, C.A., Gerschenson, L.N. and Rojas, A.M. 2009. Pumpkin (*Cucurbita moschata* Duchesne ex Poiret) mesocarp tissue as a food matrix for supplying iron in a food product. Journal of Food Engineering 92: 361-369.

Del Valle, J. M., Cuadros, T. R. M. and Aguilera, J. M. 1998. Glass transition and shrinkage during drying and storage of osmosed apple pieces. Food Research International 31(3): 191–204.

Dutta, D., Dutta, A., Raychaudhuri, U. and Chakraborty, R. 2006. Rheological characteristics and thermal degradation kinetics of beta-carotene in pumpkin puree. Journal of Food Engineering 76, 538–546.

González, E., Montenegro, M. A., Nazareno, M. A. and Lo´pez de Mishima, B. A. 2001. Carotenoid composition and vitamin A value of an Argentinian squash (*Cucurbita moschata*). Archivos Latinoamericanos de Nutricio´n 51(4): 395–399.

Gracia, C.C., Mauro, M.A. and Kimura, M. 2007. Kinetics of osmotic dehydration and air-drying of pumpkins (*Cucurbita moschata*). Journal of Food Engineering 82: 284-291.

Heredia, A., Peinado, I., Barrera, C. and Andrés Grau, A. 2009. Influence of process variables on colour changes, carotenoids retention and cellular tissue alteration of cherry tomato during osmotic dehydration. Journal of Food Composition and Analysis 22: 285-294.

Kowalska, H., Lenart, A. and Leszczyk, D. 2008. The effect of blanching and freezing on osmotic dehydration of pumpkin. Journal of Food Engineering 86: 30-38.

Kumar, H. S. P., Radhakrishna, K., Nagaraju, P. K. and Rao, D. V. 2001. Effect of combination drying on the physico-chemical characteristics of carrot and pumpkin. Journal of Food Processing Preservation 25: 447–460.

Lazerides, H. N., Gekas, V. and Mavroudis, N. 1997. Apparent mass diffusivities in fruit and vegetable tissues undergoing osmotic processing. Journal of Food Engineering 31: 315–324.

Lombard, G.E., Oliveira, J.C., Fito, P. and Andrés, A. 2008. Osmotic dehydration of pineapple as a pre-treatment for further drying. Journal of Food Engineering 85: 277-284.

Marek, G., Radzanowska, J., Danilcenko, H., Jariene, E. and Cerniauskiene, J. 2008. Quality of pumpkin cultivars in relation to sensory characteristics. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 36 (1): 73-79.

Mayor, L., Moreira, R., Chenlo, F. and Sereno, A. M. 2006. Kinetics of osmotic dehydration of pumpkin with sodium chloride solutions. Journal of Food Engineering 74(2): 253–262.

Mayor, L., Pissarra, J. and Sereno, A.M. 2008. Microstructural changes during osmotic dehydration of parenchymatic pumpkin tissue. Journal of Food Engineering 85: 326–339.

Nawirska, A., Figiel, A., Kucharska, A.Z., Sokół-Łętowska, A. and Biesiada, A. 2009. Drying kinetics and quality parameters of pumpkin slices dehydrated using different methods. Journal of Food Engineering 94: 14-20.

Pan, Y. K., Zhao, L. J., Zhang, Y., Chen, G. and Mujumdar, A. S. 2003. Osmotic dehydration pretreatment in drying of fruits and vegetables. Drying Technology 21(6): 1101–1114.

Park, K.J., Bin, A. and Reis Bord, F.P. 2002. Drying of pear d'Anjou with and without osmotic dehydration. Journal of Food Engineering 56: 97-103.

Pokharkar, S. M., Prasad, S. and Das, H. 1997. A model of osmotic concentration of banana slices. Journal of Food Science and Technology 34: 230–232.

Prothon, F. and Ahrné, L.M. 2004. Application of the Guggenheim, Anderson and De Boer model to correlate water activity and moisture content during osmotic dehydration of apples. Journal of Food Engineering 61: 467-470.

Sereno, A.M., Moreira, D. and Martinez, E. 2001. Mass transfer coefficients during osmotic dehydration of apple single and combined aqueous solution of sugar and salts. Journal of Food Engineering 47: 43–49.

Shafafi Zenoozian, M., Feng, H., Razavi, S.M.A., Shahidi, F. and Pourreza. 2008. Image analysis and dynamic modeling of thin-layer drying of osmotically dehydrated pumpkin. Journal of Food Processing and Preservation 32: 88-102.

Shukla, B.D. and Singh, S.P. 2007. Osmo-concective drying of cauliflower, mushroom and greenpea. Journal of Food Engineering 80: 741-747.

Simal, S., Deya, E., Frau, M. and Rossello, C. 1997. Simple modelling of air drying curves of fresh and osmotically pre-dehydrated apple cubes. Journal of Food Engineering 33: 139–150.

Sujata, J. and Das, H. 2005. Modelling for moisture variation during osmo-concentration in apple and pineapple. Journal of Food engineering 66: 425-432.

Talens, P., Martı´nez-Navarrete, N., Fito, P. and Chiralt, A. 2002. Changes in optical and mechanical properties during osmodehydrofreezing of kiwi fruit. Innovative Food Science and Emerging Technologies 3: 191–

199.

Torres, J.D., Talens, P., Escriche, I. and Chiralt, A. 2006. Influence of process conditions on mechanical properties of osmotically dehydrated mango, Journal of Food Engineering 74: 240-246.

Torringa, E., Esveld, E., Scheewe, I., van den Berg, R. and Bartels, P. 2001. Osmotic dehydration as a pre-treatment before combined microwave-hot-air drying of mushrooms. Journal of Food Engineering 49: 185-191.

Uddin, M.B., Ainsworth, P. and İbanoğlu, Ş. 2004. Evaluation of mass exchange during osmotic dehydration of carrots using response surface methodology. Journal of Food Engineering 65: 473-477.

USDA National Nutrient Database for Standard Reference, 2004. Nutritional Value of Pumpkin and Winter Squash. Release 17.

Vijayanand, P., Chand, N. and Eipeson, W.E. 1995. Optimization of osmotic dehydration of cauliflower. Journal of Food Processing and Preservation 19: 229-242.