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Determination of Optimum Osmotic Dehydration As a Pretreatment in Hot Air Drying of Turnip Slices By Response Surface Methodology (RSM)

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Abstract
The objective of the present study was to investigate the effect of concentration of osmotic solution (30, 45 and 60%, w/w), temperature osmotic solution (30, 40 and 50°C), immersion time (4, 5 and 6 h) on water loss (WL), solids gain (SG), weight reduction (WR), vitamin C content, shrinkage, rehydration ratio (RR), and color indexes (L, a, b) during osmotic dehydration-drying of turnip slices. Response surface methodology (RSM) was also used to find out the optimum condition. The results showed that during osmotic dehydration of turnip samples, the variables of temperature of osmotic solution, solution concentration and time of immersion had significant effects on mass transfer parameters (WL, SG, and WR), vitamin C content, shrinkage, RR, and color index (L). Optimal conditions of osmotic dehydration for turnip were found to be: solution temperature of 45 °C, osmotic solution concentration of 58.29, and immersion time of 20 min. Under these conditions, the amounts of WL, SG, WR, shrinkage, rehydration ratio (RR), vitamin C content, and color indexes (L, a, b) were 83.10, 12.91 and 70.19%, 27.76, 4.19 and 11.64 (mg/100 g solids), 33.85, 25.49 and 15.91, respectively. The results of this study can be used in the minimal processing of turnips slices using osmotic dehydration and subsequent drying of samples.

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Optimum condition
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Turnip

Introduction
Turnip (*Brassica Napus L.*) has active biological compounds such as flavonoids, indole alkaloids, and sterol glycosides (Alizadeh, Ghiamirad, & Ebrahimiasl, 2014). Also, it is a valuable source of calcium and magnesium that prevents dangerous diseases such as cancer (Gharehbeglou *et al.*, 2014). According to the limited shelf life of this product in the agricultural products depots as well as wastes after cultivation, to increase shelf life, this product can be exposed to osmotic dehydration or drying processes. Over the last decade, food production with moderate humidity using osmotic dehydration has been taken into consideration due to minimal processing

(low temperature) (Ahmed, Qazi, & Jamal, 2016). Osmotic dehydration is a process to decrease food humidity through immersion in osmotic solutions (usually with 30 to 70% concentrations) (Yadav & Singh, 2014). This process is used as a pretreatment for many food preservation processes, especially hot air drying (Shahidi, Mohebbi, Noshad, Ehtiati, & Fathi, 2012). Osmotic dehydration has disadvantages over other methods such as use of lower temperatures, better color, taste, and aroma preservation, and nutritional value (Yadav & Singh, 2014).

Different studies on osmotic dehydration have shown that parameters such as temperature and osmotic solution concentration, dehydration time, shape and size of the food product, and the ratio of the osmotic solution to the sample have considerable effects on mass transfer phenomenon during the osmotic dehydration (Chandra & Kumari, 2015). It has been reported that the use of high osmotic concentrations as pretreatment to dry with hot air leads to increased water loss (WL) and solids gain (SG), (Shahidi *et al*., 2012). Moreover, in another study, it is shown that increased osmotic solution temperature leads to increased WL and SG over the osmotic dehydration process of pineapple slices (Ramallo & Mascheroni, 2005). However, studies show that in a certain osmotic concentration, WL and SG may decrease due to various factors such as structural changes or stiffness of surface layers and barriers against water loss by solid layers (Giraldo, Talens, Fito, & Chiralt, 2003; Teles *et al*., 2006; Yadav & Singh, 2014).

The response surface methodology (RSM) is a set of statistical methods that have ability to analyze multi-parameter equations and expand mathematical models that predict simultaneous assessment of the effect of independent variables on dependent variables and optimization of different processes (Rafigh, Yazdi, Vossoughi, Safekordi, & Ardjmand, 2014). In recent years, RSM has been widely used to promote and optimize different processes in food industry such as osmotic dehydration (Derossi, Severini, Del Mastro, & De Pilli, 2015). Indeed, by using RSM, it is possible to determine optimal conditions of parameters that affect osmotic dehydration and as a result, increase the product quality and dehydration process outcome. According to previous studies, no study has been conducted on combined treatment of osmotic dehydration-turnip drying to reduce moisture content and increase its shelf life as optimize process conditions. Therefore, the objective of the present study is to investigate the simultaneous effect of osmotic process conditions including concentration and osmotic solution temperature and immersion time in osmotic solution on mass transfer parameters such as WL, SG, and weight reduction (WR) on turnip slices as well as physical and nutritional properties (vitamin C, the ratio of reabsorption and shrinkage) and color indicators (b, a, L). Finally, optimal osmotic dehydration process conditions were determined using RSM.

Materials and methods

Turnip and sugar with nutritional grade were bought from the market. The main equipment included oven, (Memert, China), bain-marie (Memert, China), digital scale with an accuracy of 0.0001 g (AND HR200, Japan), and desiccator and caliper (Mhar Company, Germanym, with an accuracy of 00.01 mm).

Methods

Sample preparation

To remove surface soil, fresh turnip samples were washed. After separating the wasters with catheter, slices (5 mm) were prepared and immediately treated with osmotic dehydration process.

Drying and osmotic dehydration

The osmotic dehydration process was carried out in a beaker containing sucrose osmotic solution. To prepare sucrose osmotic solution with brixes 30, 45, and 60, a specific amount of sugar or sucrose was poured into the beaker. Then, using distilled water, the beaker containing sucrose reached the desirable level and by stirring, sucrose was dissolved in water and the osmotic solution was prepared. For osmotic dehydration, samples were transferred to the beaker containing osmotic solution and this process was carried out for 4, 5, and 6 h at different temperatures (30, 40, and 50 °C). Immersion concentrations in osmotic solutions and temperatures were determined according to the primary tests. To control osmotic solution temperature, bain-marie was used. In the end of the osmotic dehydration process, samples were removed from the solution and washed with distilled water for 30 seconds and the surface moisture was filtered. In the next step, the samples were distributed and parameters including WL, SG, and WR were calculated using Eq. (1), (2) and (3), (Kek, Chin, & Yusof, 2013).

$$WL = \frac{W_i \times X_i - W_f \times X_f}{W_i} \times 100 \quad (1)$$

$$SG = \frac{W_f(1 - X_f) - W_i(1 - X_i)}{W_i} \times 100 \quad (2)$$

$$WR = WL - SG \quad (3)$$

W_i: initial sample mass (g); W_f: sample mass after osmotic dehydration (g); X_i: initial moisture (percent, based on moisture); X_f: sample moisture after osmotic dehydration (percent, based on moisture); WL: WL (percent, g for 100 g of the initial sample); SG: solid gravity absorption (percent, g for 100 g of the initial sample); WR: weight reduction (percent, g for 100 g of the initial sample).

By the end of the osmotic dehydration pretreatment, samples were dried under the temperature of 70 °C to reach the dry weight.

Measuring the moisture content and the solid gravity

Measurement of moisture and solid content of fresh samples and osmotic standards was according to AOAC (2000) standard, No. 931.04.

Measurement of vitamin C

Vitamin C of turnip slices was measured to investigate the effect of osmotic pretreatments on vitamin C content in the final product according to the Iranian national standard of 5609 after drying with hot air (Iranian National Standardization Organization [ISIRI], 2000).

Rehydration

To measure rehydration of samples, a specific weight of the dried samples was exposed to a temperature of 95 °C for 20 min based on osmosis-hot air method. Then, rehydration capacity was calculated using Eq. (4):

$$RR = \frac{W_r}{W_d} \quad (4)$$

W_r: sample weight (g); W_d: the dried weight of the sample used in rehydration test (g).

Shrinkage

Shrinkage percentage was measured according to fluid transfer (toluene) method (Alam, Amarjit, & Sawhney, 2010; Noshad, Mohebbi, Shahidi, & Ali Mortazavi, 2012). To calculate the shrinkage, Eq. (5) was used:

$$S = \frac{V_0 - V}{V_0} \times 100 \quad (5)$$

V_0: fresh sample volume (mL); V: final sample volume (dried) (mL).

Color indicators

To measure color, image processing technique was used. A small amount of each sample was placed on a uniform surface in a color recognition device. To take image with a digital camera, the distance between the camera and the sample was 20 cm. Then, in the Photoshop software, L, a, and b rates were obtained (Sutar & Gupta, 2007).

The experimental design and statistical analysis

To investigate the effect of osmosis dehydration on WL, WR, SG, vitamin C content, shrinkage, rehydration ratio (RR), and L, a, and b indicators, RSM was used.

The Box-Behnken design including osmotic solution temperature (30, 40, and 50 °C), osmotic solution concentration (30, 45, and 60%, w/w), and immersion time (4, 5, and 6 h) with 17 treatments and 5 replications at the central points was used. The coded and real rates of independent variables are presented in Table (1). Data were analyzed using Design Expert 6.0.2. The empirical data were fitted by the second-order polynomial model.

$$Y=b_0+b_1\,A+b_2\,B+b_3\,C+b_{11}\,A^2+b_{22}\,B^2+b_{33}\,C^2+b_{12}\,AB+b_{13}\,AC+b_{23}\,BC \quad (6)$$

B_n: regression coefficients for constant coefficient factors (b_0), linear effect coefficient (b_1, b_2, and b_3), second order effect coefficient (b_{11}, b_{22}, and b_{33}), and the interaction effect (b_{23}, b_{13}, and b_{12}).

Y: dependent variables or desirable responses including WL, SG, and WR.

Table 1. Real and coded levels of the independent variables of osmotic dehydration process of turnip slices

Independent variables	Coded and real values		
	-1	0	+1
Temperature (A)	30	40	50
Osmotic solution concentration (B, %)	30	45	60
Process time (C, hour)	4	5	6

Results and discussion

Mass transfer parameters rates (WL, SG, and WR) in osmotic dehydration of turnip slices are shown in Table (2). According to Table (3), the results of the analysis of variance showed that the second order model was significant for the responses (except b, $P>0.05$) that indicates the appropriateness of the model used to predict the effect of the independent variables on the responses. In response surface optimization, the suitable model is selected according to the significance of F test ($P<0.05$), insignificance of lack of goodness of fit ($P>0.05$), high explanatory coefficient (R^2), and lower variation coefficient (CV). In the current study, high explanatory coefficient for responses ($R^2>0.94$) and variation coefficient (CV) lower than 4% for the fitted model, indicate acceptable consistency between the used regression model and their high accuracy in predicting the dependent variables rates (Table 3).

Table 2. Experimental conditions and response rates in osmotic dehydration process of turnip slices

Treatment	Independent variables			The dependent variables								
	A	B	C	WL	SG	WR	S	RR	Vit C	L	a	b
1	30	30	5	66.92	10.59	56.33	28.42	3.67	13.49	31.16	27.89	17.01
2	30	45	4	69.54	11.72	57.82	28.26	4.05	12.35	32.78	26.91	16.93
3	40	30	6	73.69	11.06	62.09	28.54	3.88	13.06	33.93	26.20	18.53
4	30	60	5	79.70	12.66	67.04	27.86	4.14	11.53	30.28	23.81	17.49
5	50	60	5	84.93	13.04	71.89	27.47	4.32	10.34	34.03	25.18	16.82
6	40	45	5	78.05	12.87	65.18	28.58	4.15	11.18	32.29	24.59	18.53
7	40	30	4	66.18	10.33	55.85	28.82	3.41	13.75	32.38	24.12	17.68
8	40	60	4	75.51	12.23	63.28	28.35	4.41	11.86	31.75	23.69	19.26
9	40	45	5	78.60	12.82	65.78	28.57	4.53	11.51	34.39	24.58	18.36
10	40	45	5	78.15	12.88	65.27	28.54	4.54	11.44	33.84	22.19	18.39
11	40	45	5	78.27	12.79	65.48	28.34	4.53	11.48	32.53	24.63	17.39
12	50	45	6	84.82	12.92	71.90	27.81	4.61	10.18	37.08	23.12	17.52
13	30	45	6	77.09	12.34	64.75	28.31	4.39	11.74	32.26	26.82	16.69
14	40	60	6	86.09	13.44	72.65	27.83	4.49	11.05	38.35	25.06	16.41
15	50	45	4	74.23	12.01	62.22	27.88	4.07	11.84	34.49	25.36	16.83
16	50	30	5	76.48	11.03	65.45	27.84	3.29	13.04	30.47	23.41	17.29
17	40	45	5	78.44	12.64	65.80	28.46	4.42	10.96	33.70	22.16	18.33

A: osmotic solution temperature; B: osmotic solution concentration (%); C: process time (hour); WL (%); SG (%); WR (%); S: shrinkage (%); RR: rehydration ratio (%); Vitamin C (mg/100 g of the dry matter).

Table 3. Analysis of variance of the second-order polynomial model

Sources Change	Degrees of freedom	Value F								
		WL	SG	WR	S	RR	Vit C	L	a	b
Model	9	516.84^{**}	13.79^{**}	385.66^{**}	2.10^{**}	2.44^{**}	16.49^{**}	62.17^{*}	29.81^{ns}	8.49^{*}
A	1	92.54^{**}	0.35^{**}	81.40^{**}	0.42^{**}	0.0002^{ns}	1.72^{**}	11.49^{*}	8.73^{ns}	0.01^{ns}
B	1	230.69^{**}	8.73^{**}	154.35^{**}	0.55^{**}	1.20^{**}	9.15^{**}	5.23^{ns}	1.88^{ns}	0.02^{ns}
C	1	164.07^{**}	1.50^{**}	129.76^{**}	0.08^{ns}	0.25^{*}	1.77^{**}	13.05^{*}	0.15^{ns}	0.34^{ns}
A^2	1	0.061^{ns}	0.25^{**}	0.15^{ns}	0.89^{**}	0.12^{*}	0.01^{ns}	3.46^{ns}	5.22^{ns}	4.12^{**}
B^2	1	5.79^{**}	2.22^{**}	1.11^{*}	0.08^{ns}	0.69^{**}	3.00^{**}	3.86^{ns}	0.45^{ns}	0.005^{ns}
C^2	1	13.05^{**}	0.40^{**}	9.72^{**}	0.003^{ns}	0.001^{ns}	0.31^{ns}	12.31^{*}	2.75^{ns}	0.16^{ns}
AB	1	4.68^{**}	0.0008^{ns}	4.55^{**}	0.009^{ns}	0.07^{ns}	0.13^{ns}	4.92^{ns}	8.55^{ns}	0.22^{ns}
AC	1	2.31^{**}	0.02^{ns}	1.89^{*}	0.003^{ns}	0.009^{ns}	0.27^{ns}	2.41^{ns}	1.15^{ns}	0.21^{ns}
BC	1	2.35^{**}	0.05^{*}	2.44^{**}	0.01^{ns}	0.03^{ns}	0.003^{ns}	6.37^{ns}	0.12^{ns}	3.24^{**}
left over	7	-	-	-	-	-	-	-	-	-
Lack of fit	3	0.73^{ns}	0.02^{ns}	0.94^{ns}	0.08^{ns}	0.039^{ns}	0.16^{ns}	6.27^{ns}	4.81^{ns}	0.99^{ns}
Net error	4	-	-	-	-	-	-	-	-	-
Total	16	-	-	-	-	-	-	-	-	-
Coefficient of explanation (R^2)	-	0.9982	0.9954	0.9967	0.9438	0.9422	0.9766	0.8672	0.7151	0.8267
Coefficient of variation (CV)	-	0.47	0.78	0.66	0.47	3.51	2.01	3.50	5.28	2.87

** Significance at a probability level of 1%, significant at a probability level of 5%.
* Significance at a probability level of 1%, significant at a probability level of 1%.
ns: no significance

Water Loss (WL)
According to Table (3), concentration (B), time (C), and temperature (A) have the largest positive effects on WL. All linear effects, second-order (except the effect of the osmotic solution temperature A^2) and the effects of independent variables on WL were positive. Eq. (7) shows the second-order polynomial model to predict WL rate according to the coded rates after removing the insignificant factors.

$$WL=+78.30+3.40\ A+5.37\ B+4.53\ C-1.17\ B^2-1.76\ C^2-1.08\ AB+0.76\ AC+0.77\ BC \quad (7)$$

The effect of independent variables of osmotic solution temperature-osmotic solution concentration, osmotic solution temperature-immersion time, and osmotic solution concentration-immersion time on WL response is shown as a response surface chart in Fig. (1). About WL, temperature (A) only had a positive linear effect (P<0.01) and the existence of low upward curvature in interaction curves of the interaction effect of temperature-concentration, temperature-time, and concentration-time shows this fact.

Fig. (1) shows that with increased concentration, dehydration time, and osmotic solution temperature, WL increases but in higher concentrations and dehydration time, WL tone decreases compared with the initial times of the process. Generally, higher temperatures lead to swallowing and plasticity of cellular membrane and rapid release of moisture. Also, at higher temperatures, osmotic solution viscosity decreases. Therefore, due to reduced viscosity, moisture release is performed better (Sutar & Gupta, 2007). The positive effect of increased concentration can be related to the increased osmotic pressure due to increased intracellular concentration and osmotic solution difference at higher concentrations (Lazarides, Katsanidis, & Nickolaidis, 1995). The above results are consistent with the results of other studies (Ebrahim Rezagah, Kashaninezhad, Mirzaei, & Khomeiri, 2009; Falade, Igbeka, & Ayanwuyi, 2007; Singh, Panesar, Nanda, & Kennedy, 2010). High water outflow rate in the early osmosis stages and its reduction over time are reported by (Eren & Kaymak-Ertekin, 2007).

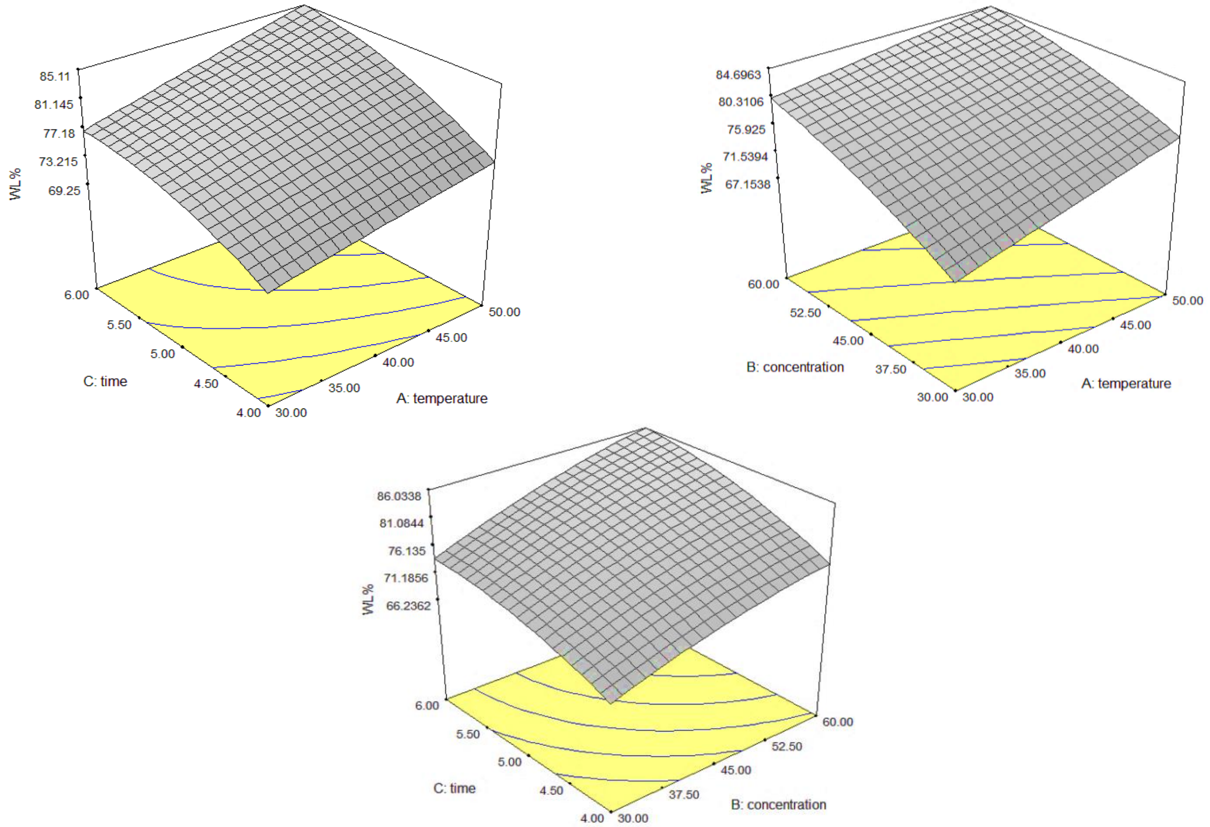

Fig. 1. The interaction effect of independent variables of osmotic solution temperature - osmotic solution concentration - osmotic solution temperature - immersion time - osmotic solution concentration - immersion time on WL (%) of turnip slices

As the osmotic dehydration process continues, due to the loss of moisture from the product tissue and entrance of sucrose, osmotic pressure difference and concentration difference between turnip tissue and osmotic solution reduce. Therefore, WL tone reduces gradually. On the other hand, rapid moisture removal and SG lead to structural changes and stiffness of surface layers. Therefore, resistance against mass transfer increases (Eren & Kaymak-Ertekin, 2007; Vieira, Pereira, & Hubinger, 2012). Giraldo *et al.* (2003) reported that excessive increase in common medlar osmotic solution concentration leads to lower WL.

Solid Gravity (SG)

SG rate during osmotic dehydration is dependent on all three parameters of osmotic solution temperature, osmotic solution concentration, and immersion time. Table (3) shows that all linear effects and second-order effects of the independent variables have a significant effect on SG. However, according to the numerical value of the coefficient, its effect was smaller than other significant sentences. But the negative coefficients about the second-order sentences show that excessive increase in this parameter leads to reduced SG rate. These effects can be observed in Fig. (2).

Fig. (2) shows the effects of independent variables on SG response. As can be observed, with increased concentration, dehydration time and osmotic solution temperature, SG rate increases rapidly but gradually decreases. Also, the observed curvature for the independent variables in Fig. (2) is consistent with the second-order the effects of all three independent variables in Table (3).

The driving force concentration difference is mass transfer to absorb sucrose (Rastogi & Raghavarao, 2004).

Enhancement of mass transfer properties due to increased temperature and concentration which may affect increased SG of turnip. As stated about WL, increased temperature affects cell membrane permeability and can lead to SG penetration into fruit or vegetable tissues. Other researchers reported that increased temperature leads to simultaneous increase in WL and SG (İspir & Toğrul, 2009). In the current study, increased osmotic concentration leading to increased SG but then, SG rate decreased. Increased SG and increased concentration can be due to increased osmotic pressure gradient (Phisut, 2012).

Teles *et al*. (2006) reported that mass transfer reduction in high osmotic solution concentrations is due to barrier against WL by layers of SG on the melon surface. Observation of the negative effect of increased temperature on SG and WL can be due to cell wall permeability destruction (Yadav & Singh, 2014). In another study, it was reported that if the dehydration process continues, mass transfer gradient decreases and equilibrium rates are obtained (Ebrahim Rezagah *et al*., 2009). Therefore, according to the negative coefficient of the second-order sentence of time (C^2), reduced SG during long osmotic dehydration is not expected. About the effect of process time on SG (Fig. 2), in maximum concentration in use, with increased osmotic dehydration time around 5 to 6 h, SG rate reaches to the maximum level and with further increase in time up to 6 h, no significant change is resulted in SG rate.

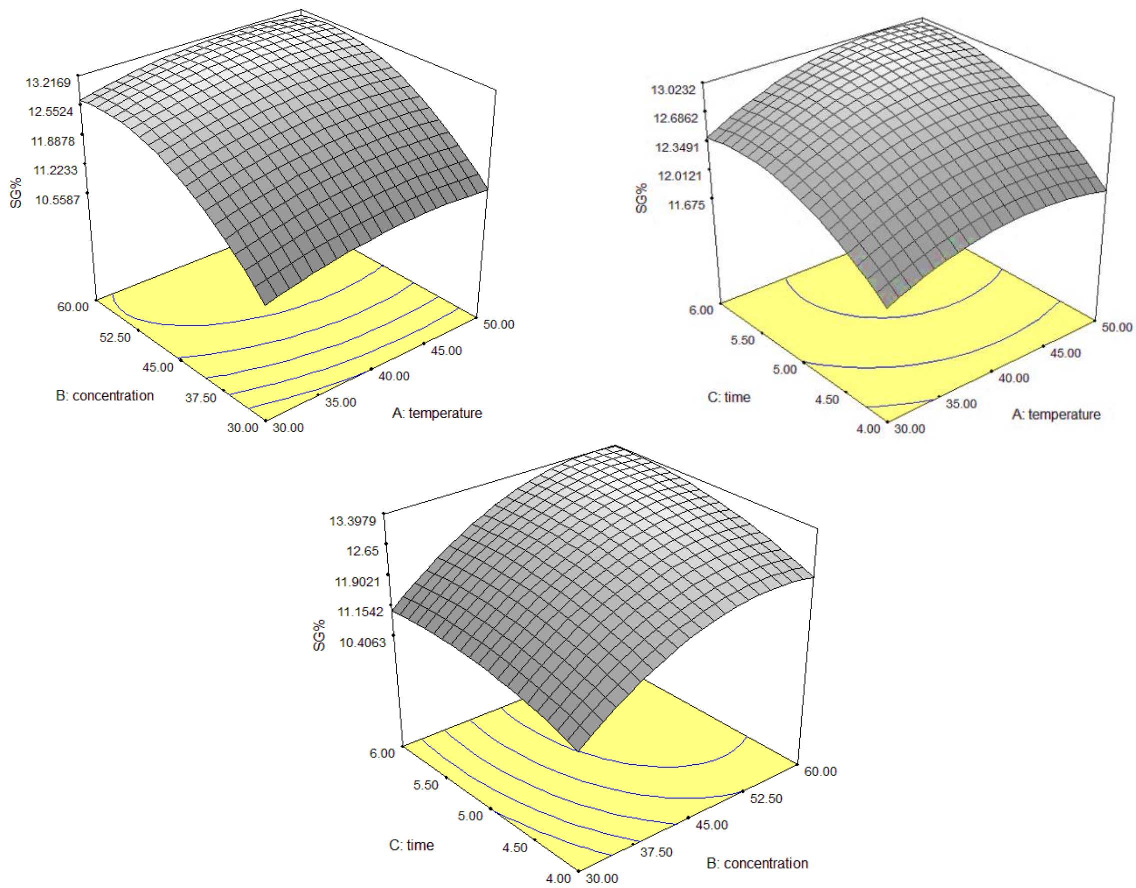

Fig. 2. The interaction effect of osmotic solution temperature - osmotic solution concentration - osmotic solution temperature - immersion time - osmotic solution concentration - immersion time on SG (%) of turnip slices

Weight Reduction (WR)

According to Table (3), all linear, second-order, and interaction effects of independent variables have a significant effect on WR. The first-order sentences of time (C), concentration (B), and temperature (A) have the largest positive effect on WR during osmotic dehydration process. The second-order sentences of time (C^2) and osmotic solution concentration (B^2) had the largest negative effect on WR rate. This finding shows that during long osmotic dehydration process or with excessive increased solution concentration, WR rate decreases. However, according to the numerical coefficients of the second-order sentences, increased concentration has a slight negative effect compared with the second-order effect of time (Fig. 3). Moreover, the interaction effect of temperature-concentration (AB) has a negative effect and the interaction effects of temperature-time (AC) and concentration-time (BC) have a positive effect on WR. Eq. (9) shows the polynomial model used according to the coded rates to predict WR rates after removing sentences with insignificant effects:

$$WR = +65.50 + 3.19\,A + 4.39\,B + 4.03\,C - 0.51\,B^2 - 1.52\,C^2 - 1.07\,AB + 0.69\,AC + 0.78\,BC \quad (9)$$

In the osmotic dehydration process, WR is defined as WL and SG difference. Therefore, similar to the effects observed for linear sentences of concentration, temperature, and time in increasing WL, the trend observed in WR is justifiable. Vieira *et al*. (2012) reported that with increased osmotic solution concentration and temperature, WL and WR increase. Fig. (3) shows that with simultaneous increase in temperature-time and concentration-time, WR rate increases during turnip osmotic dehydration. However, in longer processes, increasing tone in WR decreases.

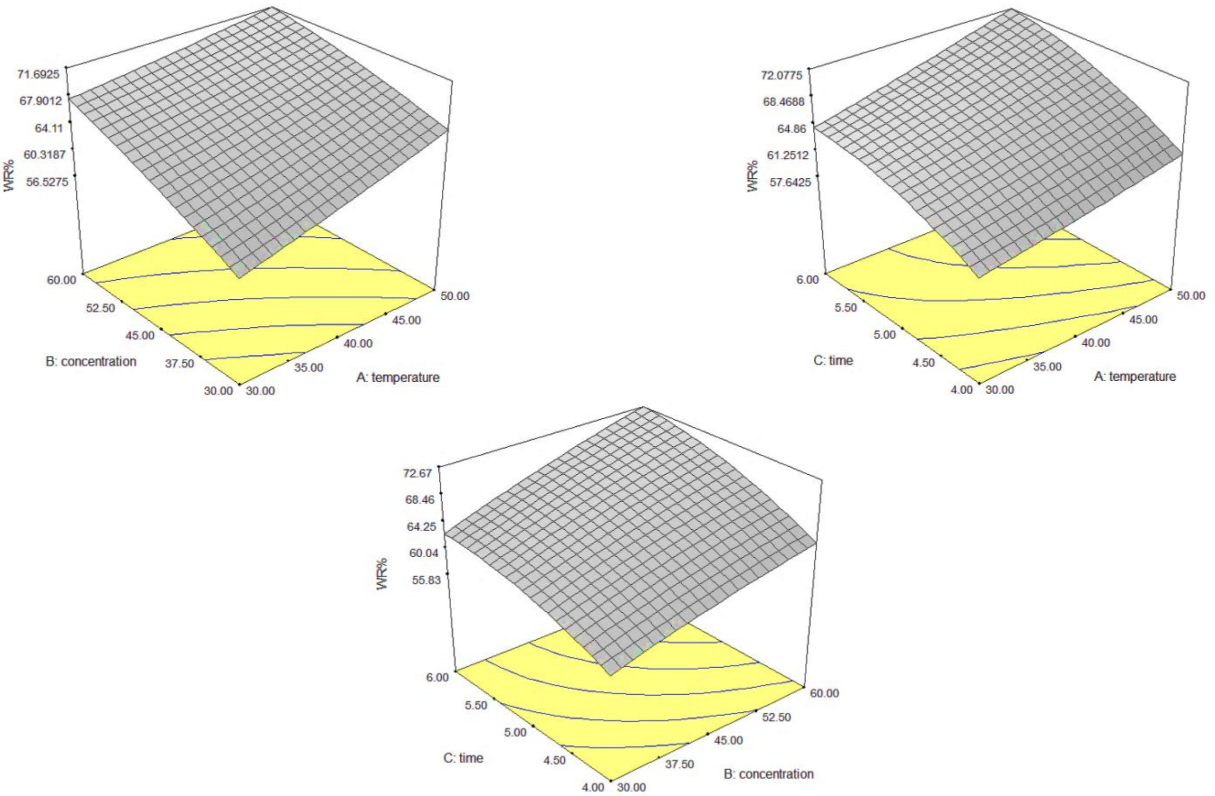

Fig. 3. The interaction effect of the independent variables of osmotic solution temperature - osmotic solution concentration - osmotic solution temperature - immersion time and osmotic solution concentration - immersion time on WR (%) of turnip slices

Shrinkage

Shrinkage is one of the important parameters that affects structural properties of the food product. According to Table (3), only the linear effect of temperature (A) and concentration (B) and the second-order effect of temperature (A^2) have a significant effect of shrinkage rate (A^2) and osmotic solution concentration (B^2) has a negative effect on shrinkage. The negative effects of the significant sentences show that with increased temperature and concentration of the osmotic solution, shrinkage increased and then decreases and this can be deduced from Fig. (4). Also, the curvature observed in the graph shows the interaction effect of temperature-concentration and temperature-time consistent with the significance of the second-order effect of temperature (A^2) in Table (3), (Fig. 4). Eq. (10) shows the polynomial model used according to the coded rates to predict shrinkage rates after removing sentences with insignificant effects.

$$S=+28.50-0.23\,A-0.26\,B-0.46\,A^2 \quad (10)$$

Shahidi *et al*. (2012) in investigating shrinkage of banana leaves during osmotic-drying dehydration reported that with increased osmotic solution concentration, SG increased and shrinkage decreased.

According to the positive effect of increased concentration and temperature on increased SG, decreased shrinkage at higher osmotic concentrations can be due to increased turnip tissue resistance against deformation as a result of sugar penetration. Indeed, solid matters that penetrate into the interstitial space, fill the gaps and prevent shrinkage during hot air drying. Moreover, Shahidi *et al*. (2012) stated that with increased osmotic solution concentration, a hard crystal layer is formed on banana. These researchers believed that this layer is the result of hot air drying and decreased shrinkage. It seems that the above assumption about turnip osmotic drying is true in the current study.

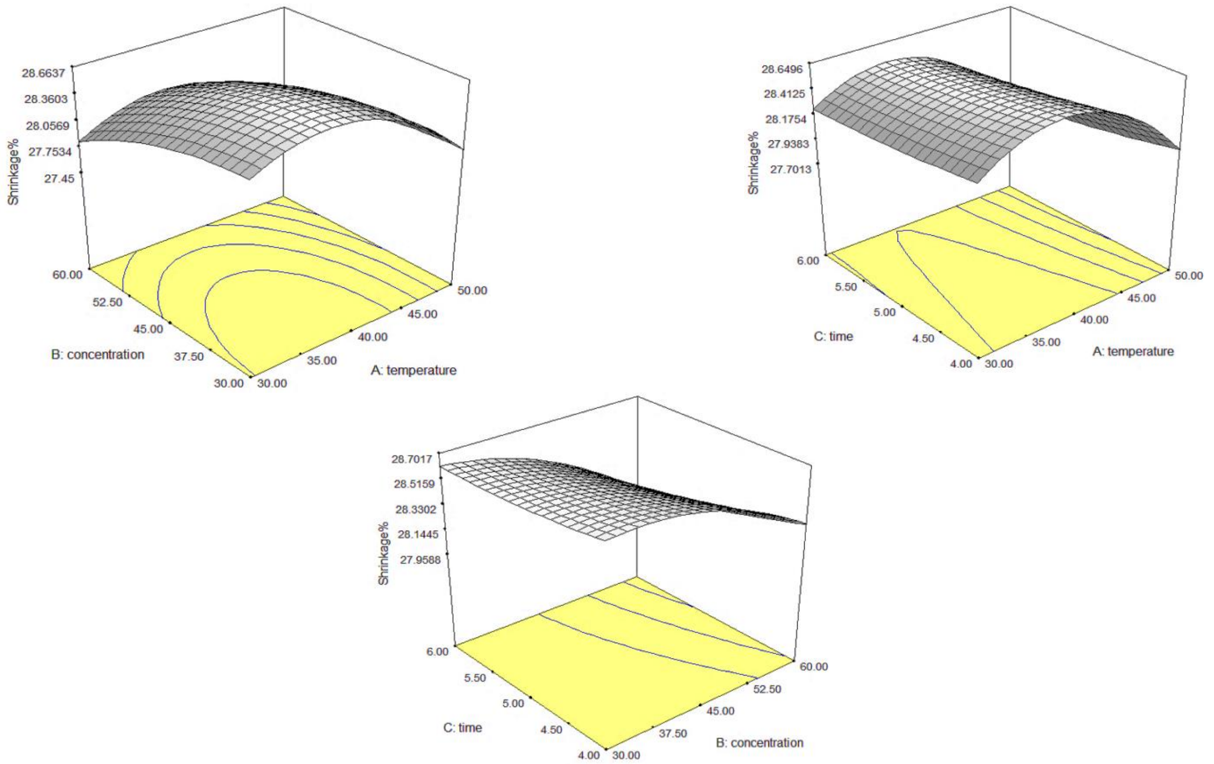

Fig. 4. The interaction effect of the independent variables of osmotic solution temperature - osmotic solution concentration - osmotic solution temperature - immersion time and osmotic solution concentration - immersion time on SR (%) of turnip slices

Rehydration

Rehydration is one of the qualitative parameters in the dehydrated product. The results of Table 3 show that only the linear effects of concentration (B) and time (C) as well as the second-order effects of temperature (A^2) and concentration (B^2) have a significant effect on RR. The first-order sentences of concentration and time had a positive effect and the second-order sentences of temperature (A^2) and concentration (B^2) has a negative effect on RR. These observations showed that with increased concentration and dehydration temperature, RR increases, but for higher concentrations and temperatures, RR decreases. These findings can be seen in Fig. (5). Also, lack of curvature for time in temperature-time and concentration-time chart (Fig. 5) is consistent with the insignificant effect of time (C^2) in Table (3). Eq. (11) shows a polynomial model according to the coded rates to predict RR after removing sentences with insignificant effects.

$$RR = +4.43 + 0.39\,B + 0.18\,C - 0.17\,A^2 - 0.41\,B^2 \qquad (11)$$

During osmotic dehydration, SG affected cell penetration and reduced rehydration (Singh *et al*., 2010).

The above results are consistent with the findings of other researchers (Bakalis & Karathanos, 2005; Lewicki, 1998; Rastogi & Raghavarao, 2004). Previous studies show that osmotic dehydration has a negative effect on RR (Shahidi *et al*., 2012). This is due to the saturation of the bottom layer or lower dehydration of the sugar layer compared with the natural tissue of the food product.

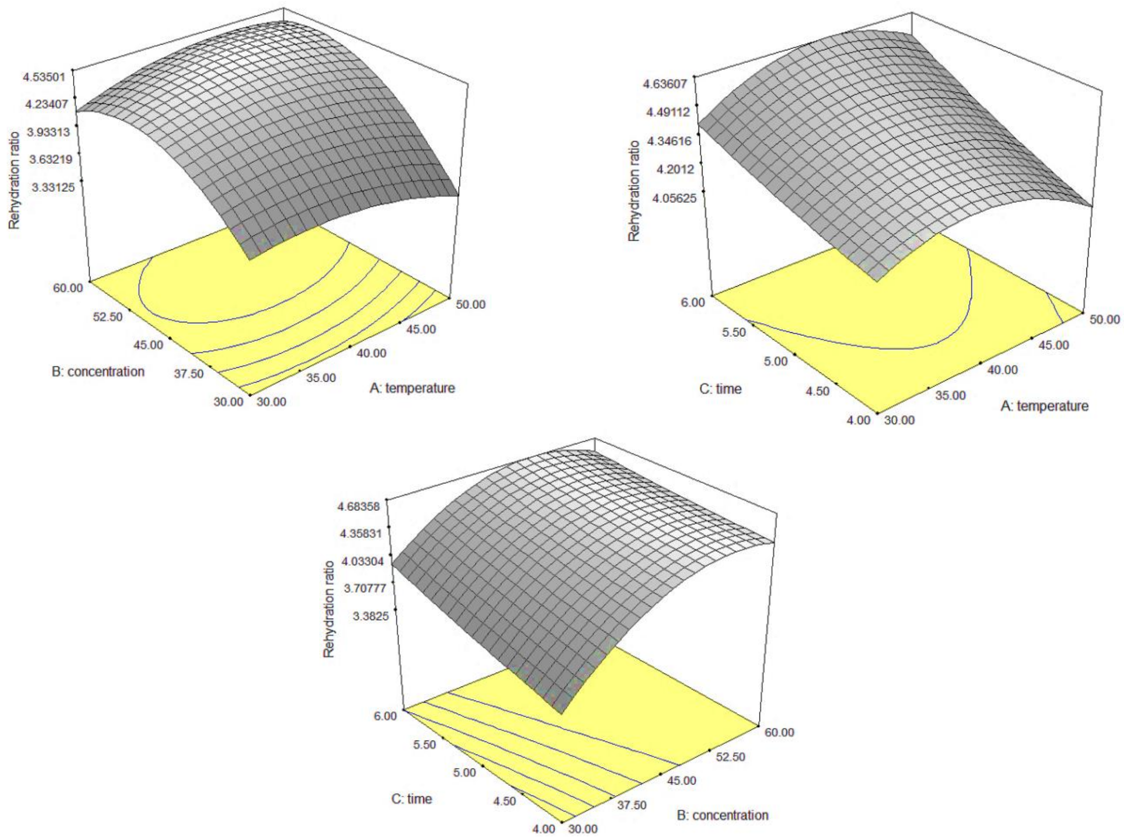

Fig. 5. The interaction effect of the independent variables of osmotic solution temperature-osmotic solution concentration-osmotic solution temperature-immersion time and osmotic solution concentration-immersion time on RR (%) of turnip slices

Vitamin C

Vitamin C content is one of the important qualitative parameters that affects the nutritional value of the processed product. The results of Table (3) about vitamin C show that only linear sentences of three variables (i.e. concentration, temperature, and time) and the second-order effect of concentration (B^2) were significant while other sentences had insignificant effects on vitamin C content and removed from the model. According to the results, the first-order effects of temperature, concentration, and time as well as the second-order effect of temperature (A^2) had a negative effect and the second-order sentences of concentration (B^2) and time (C^2) had a positive effect on vitamin C content. Eq. (12) shows the polynomial model used according to the coded rates to predict vitamin C content after removing sentences with insignificant effects.

$$\text{Vit C}=+11.31-0.46\,A-1.07\,B-0.47\,C+0.84\,B^2+0.27\,C^2 \quad (12)$$

Among significant sentences, temperature (A) and time (C) or concentration (B) have the largest negative effect on vitamin C content. The findings show that with increase in these parameters, especially concentration, vitamin C content in turnip decreases (Fig. 6). Azoubel *et al*. (2009) reported vitamin C drop about apple osmotic dehydration. According to high solubility of vitamin C in water, its drop during osmotic dehydration with WL is not unexpected.

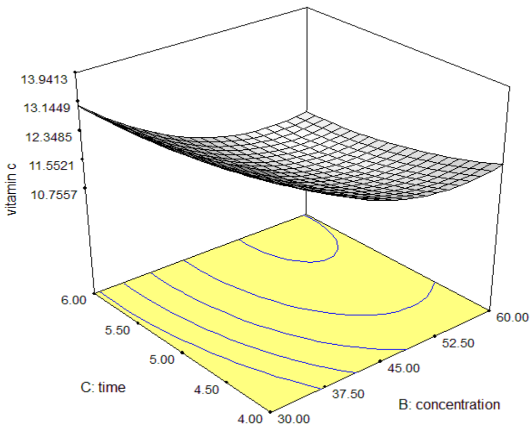

Fig. 6. The interaction effect of the independent variables of osmotic solution temperature-osmotic solution concentration-osmotic solution temperature-immersion time and osmotic solution concentration-immersion time on vitamin C content (mL/100 g of dry matter) of turnip slices

Color indicators

According to Table (3), the fitted model was significant for b indicators. About light (L), only linear sentences of temperature (A), time (C) and the second-order sentence of time (C^2) showed a significant effect. Eq. (13) shows the polynomial model used according to the coded rates to predict L after removing the sentences with insignificant effects:

$$L=+33.35+1.20\,A+1.28\,C+1.71\,C^2 \quad (13)$$

The positive coefficients of the significant sentences indicate increased L indicators with increased temperature (A) and time (C). The above effects can be observed in Fig. (7). According to Fig. (7), with increased concentration and temperature simultaneously, L rate increases and then decreases gradually.

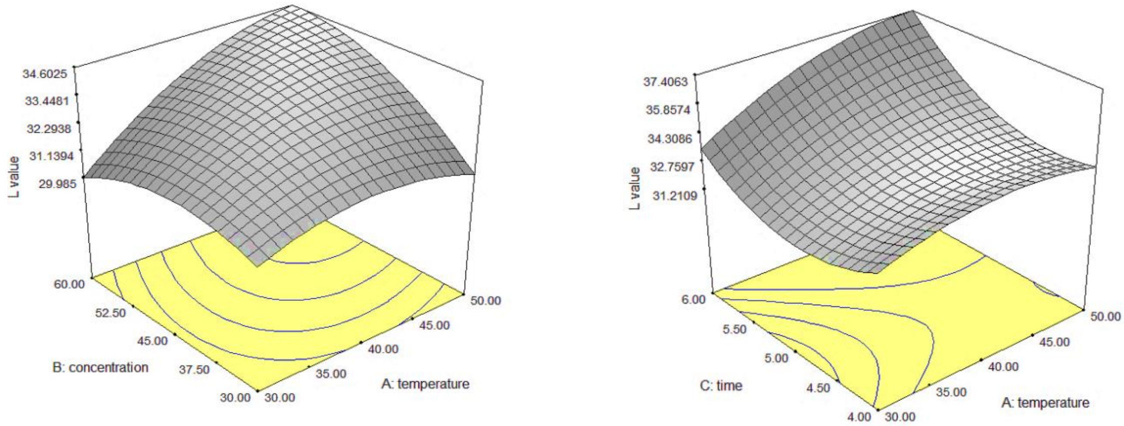

Fig. 7. The interaction effect of the independent variables of osmotic solution temperature-osmotic solution concentration-osmotic solution temperature-immersion time on L indicator of turnip slices

Also, the observed curvature for dehydration time (C) in temperature-time chart (Fig. 7) is consistent with the significance of the second-order sentence of time (C^2) in Table (3).

About parameter b, only the second-order sentence of temperature (A^2) and the interaction effect of concentration-time (BC) had a significant effect. Eq. (14) shows the polynomial model used according to the coded rates to predict b indicator after removing sentences with insignificant effects.

$$b=+18.18-0.99\,A^2-0.90\,BC \quad (14)$$

According to Fig. (8), the lowest b rate was obtained under maximum concentration-time condition. The negative effect of the interaction effect of concentration-time (BC) confirms this finding. Singh *et al*. (2010) reported similar results in optimizing osmotic dehydration. Also, the observed curvature for temperature (A) in temperature-concentration (Fig. 8) chart is consistent with the significance of the second-order sentence (A^2) in Table (3). According to Fig. (8), with increased temperature, b parameter increased and then decreased, so that maximum b was resulted in average rates of temperature and concentration.

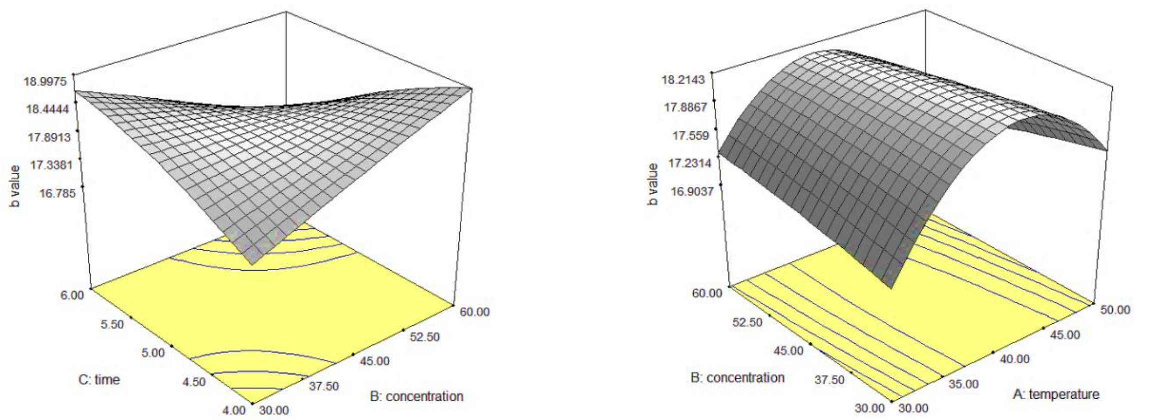

Fig. 8. The interaction effect of the independent variables of osmotic solution temperature-osmotic solution concentration-osmotic solution temperature-immersion time on b indicator of turnip slices

Optimization of the osmotic dehydration process

To achieve optimal conditions for turnip osmotic dehydration process, numerical optimization technique was used (Table 4).

According to different studies on osmotic dehydration of fruits and vegetables, this study aimed to maximize WL, WR, RR, vitamin C, and L parameters and minimize SG, shrinkage, and a and b parameters(Eren & Kaymak-Ertekin, 2007; Noshad *et al*., 2012; Vieira *et al*., 2012). Finally, using desirability function method, the optimal conditions were determined as 30.81 °C, sucrose concentration of 60%, and 6 h. The predicted rates for the responses were predicted as 83.10, 12.91, and 70.19%, 27.76, 4.19, and 11.64 (mg/100 g of dry matter), 33.85, 25.49, and 15.91 for WL, SG, WR, shrinkage, RR, vitamin C, and L, a, and C parameters. To check the accuracy of the predicted points by the second-order polynomial sentence, validation test was used. The turnip samples resulted under optimal conditions were dehydrated and dried at 70 °C. Osmotic dehydration parameters and the qualitative properties of the dried samples based on osmosis-hot air method (in three replications) were compared with the predicted conditions. The predicted error percentage for each response was calculated using Eq. (15):

$$Error(\%) = \frac{R_t - R_p}{R_p} \times 100 \quad (15)$$

R_t: real data resulted from validation test; R_p: the predicted data by the model. The results of this comparison are presented in Table (4). Table (4) shows that the presented model can predict the responses very well. The prediction error about all responses, except parameter a, was led than 10%. Therefore, the above model can be used to optimize turnip osmotic dehydration.

Table 4. The predicted and experimental results for responses in turnip osmotic dehydration

Response	The predicted results	The experimental results*	The prediction error percentage
WL	83.10	83.47±0.97	0.44
SG	12.91	12.66±0.38	-1.88
WR	70.19	70.80±1.33	0.87
Shrinkage	27.76	28.27±0.38	3.72
RR	4.19	3.97±0.14	-5.25
Vitamin C	11.64	11.66±0.70	0.17
Parameter L	33.85	33.98±0.87	0.40
Parameter a	25.49	23.26±0.82	-8.74
Parameter b	15.91	15.20±0.42	-4.42

Conclusions

In the current study, the effect of osmotic dehydration process conditions (i.e. concentration, temperature, and time)-hot air drying (70 °C) on mass transfer phenomena and physical and nutritional properties of turnip (shrinkage, RR, vitamin C, and L, a, and b parameters) were investigated. To determine optimal osmotic dehydration conditions, RSM was used. The results showed that the second-order polynomial models to predict all responses were statistically significant (except a). During osmotic dehydration of turnip samples, temperature, concentration, and time had significant effects on WR, SG, WL, vitamin C, shrinkage, RR, and L. The optimal osmotic dehydration conditions for turnip, we had osmotic solution temperature of 30.81 °C, osmotic solution concentration of 60%, and time of 6 h. Under these conditions, WL, SG, WR, shrinkage, RR, vitamin C, and L, a, and b parameters were 83.10, 12.91, and 70.19%, 27.76, 4.19, and 11.64 (mg/100 g solids), 33.85, 25.49, and 15.91. Therefore, the results of the current study can be used in turnip processing method using osmotic dehydration and drying the next samples.

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تعیین شرایط بهینهٔ آب‌گیری اسمزی به‌عنوان پیش‌تیمار در خشک‌کردن با هوای داغ برش‌های شلغم به روش سطح

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چکیده

هدف از مطالعهٔ حاضر، بررسی اثر غلظت محلول اسمزی (۳۰، ۴۵ و ۶۰ درصد وزنی/وزنی)، دمای محلول اسمزی (۳۰، ۴۰ و ۵۰ درجهٔ سانتی‌گراد) و زمان غوطه‌وری (۴، ۵ و ۶ ساعت)، بر خروج آب (WL)، جذب مادهٔ جامد (SG)، کاهش وزن (WR)، محتوی ویتامین C، چروکیدگی، نسبت بازآبپوشی (RR) و شاخص‌های رنگ (L، a و b) طی آب‌گیری اسمزی- خشک‌کردن ورقه‌های شلغم بود. روش سطح پاسخ (RSM) نیز برای یافتن شرایط بهینه مورداستفاده قرار گرفت. نتایج نشان داد که طی آب‌گیری اسمزی نمونه‌های شلغم، متغیرهای دمای محلول اسمزی، غلظت محلول و زمان غوطه‌وری تأثیر معنی‌داری بر پارامترهای انتقال جرم (WL، SG و WR)، محتوی ویتامین C، چروکیدگی، RR و شاخص رنگ (L) داشتند. شرایط بهینهٔ آب‌گیری اسمزی برای شلغم، دمای محلول اسمزی ۳۰/۸۱ درجهٔ سانتی‌گراد، غلظت محلول اسمزی ۶۰ درصد و زمان غوطه‌وری ۶ ساعت بود. تحت این شرایط، مقادیر پاسخ‌های WL، SG، WR، چروکیدگی، نسبت بازآبپوشی (RR)، محتوی ویتامین C و شاخص‌های رنگی L، a و b به‌ترتیب ۸۳/۱۰، ۱۲/۹۱ و ۷۰/۱۹ درصد، ۲۷/۷۶، ۴/۱۹ و ۱۱/۶۴ (میلی‌گرم در ۱۰۰ گرم مادهٔ خشک) و ۳۳/۸۵، ۲۵/۴۹ و ۱۵/۹۱ بود. نتایج پژوهش حاضر می‌تواند جهت فراوری حداقلی برش‌های شلغم با استفاده از آب‌گیری اسمزی و خشک‌کردن بُعدی نمونه‌ها مورداستفاده قرار گیرد.

واژه‌های کلیدی: آب‌گیری اسمزی، بهینه‌یابی، روش سطح پاسخ، شلغم