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ORIGINAL PAPER

Optimization of osmo-vacuum drying of pear (*Pyrus communis* L.) using response surface methodology

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Abstract In the two-stage optimization of the osmotic dehydration and vacuum drying of the pear slices using response surface methodology, using face-centred central composite design (FCC), it was shown that the independent variables for osmotic dehydration were temperature (25–55 °C), solution concentration (50–70 % w/w), and immersion time (60–120 min) and for vacuum drying were vacuum pressure (10–30 kPa), drying temperature (50–70 °C) and drying time (180–300 min). Statistical analysis of results showed that the linear terms of all process variables in both stages have a significant effect on the responses. The second-order polynomial models for all response variables were found to be statistically significant with high values of R^2 (>0.8). The optimum osmotic dehydration conditions for maximum water loss, minimum solute gain and maximum weight reduction were: 55 °C temperature, 50 % sucrose solution concentration, and 115 min immersion time. Dehydrated pear slices at optimized osmotic dehydration conditions were then subjected to vacuum drying. Optimum drying conditions of 10 kPa vacuum pressure, 55 °C temperature and 250 min drying time were established for vacuum drying of pear. At this optimum point, moisture content (MC), rehydration ratio and shrinkage were found to be 23.26 % (w.b.), 1.46 and 67.45 %, respectively. Separate validation experiment was conducted at the derived optimum conditions to verify the predictions and adequacy of the models. Two-stage optimization led to obtaining the best condition for production of dried quince slices with lowest MC, and shrinkage.

Keywords Osmotic dehydration · Pear · Response surface methodology · Two-stage drying · Vacuum drying

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Introduction

Pear (*Pyrus communis* L.) is a typical fruit of temperate zones, originated in the Asiatic region [1]. This fruit is natural source of vitamin C, vitamin K, copper and good source of fiber. According to FAO data, world production of pear was about 23,580,845 tonnes in 2012 and Iran was 147,000 tonnes which ranked the eighteenth [2].

The dried pear can be used for many purposes, such as in bakery products, gravies, compotes and for consumption of the dry fruit; it is also suitable to be consumed by diabetics, aged people and babies [1].

Fruit drying is a well-known process mostly used for preservation of fruit. There are many conventional drying methods in practice to dry fruits and vegetables but there is also concern about quality of the dried products and drying efficiency. Hot air drying is the most widely used method for production of dehydrated fruits and vegetables [3, 4]. High temperature and long drying time being used in conventional air drying may cause serious damage to product flavor, color, and nutrients, reducing bulk density and rehydration capacity of the dried product [5].

Vacuum drying provides an alternative to conventional atmospheric drying [6]. It allows for the removal of moisture under low pressure [7]. Vacuum expands air and water vapor present in the food and creates a frothy or puffed structure,

providing a large area-to-volume ratio for enhanced heat and mass transfer [8]. Consequently, with vacuum drying it is possible to have a higher drying rate, lower drying temperature, and an oxygen deficient processing environment [7].

Osmotic dehydration is used as a pre-treatment to many preservation processes to improve nutritional, sensorial, and functional properties of fruits without changing their integrity [9–11]. Osmotic dehydration removes water partially from fruits or vegetables immersed in a hypertonic solution. A driving force for water removal is set up because of a difference in osmotic pressure between the food and its surrounding solution. The complex cellular structure of food acts as a semi-permeable membrane [12, 13]. Sucrose, glucose, fructose, corn syrup and sodium chloride are the common osmotic agents and out of this sodium chloride solution is commonly used for vegetables and sucrose solution for fruits [14]. Sucrose has been recommended for osmotic dehydration of fruits because of its effectiveness, convenience and desired flavor [15, 16]. The food which has been osmotically dehydrated can be further processed by freezing, freeze drying, vacuum drying and air drying [17, 18].

Optimization of the dehydration process is performed to ensure rapid processing conditions yielding an acceptable quality product and a high throughput capacity [19]. Response surface methodology (RSM) is a statistical procedure frequently used for optimization studies. It uses quantitative data from an appropriate experimental design to determine and simultaneously solve multivariate problems. Equations describe the effect of test variables on responses, determine interrelationships among test variables, and represent the combined effect of all test variables in any response. This approach enables a researcher to make efficient exploration of a process or system [19, 20].

The general objective of this research was to study the osmotic dehydration pretreatment of pear cut in cylindrical form followed by vacuum drying. The specific objectives of the study were to investigate main effects of process variables on the product quality during osmotic dehydration pretreatment and final vacuum drying of pear, and optimize the process conditions of osmotic dehydration pretreatment and vacuum drying result in a product with sufficiently low moisture content (MC), high quality and consumer acceptability.

Materials and methods

Preparation of samples

Fresh pears were obtained from a local market in Mashhad, Iran and stored at refrigerator before used in the experiments. The fruits were washed, hand peeled and cut into cylinders of same dimensions (0.9 ± 0.05 cm average in height and 2.8 ± 0.2 cm average in diameter) using a manual dicer. Samples were immediately dipped into a solution consist of 1 g/100 ml ascorbic acid and 0.2 g/100 ml citric acid for 5 min to prevent enzymatic browning reactions [21], drained and immersed in previously prepared osmotic solutions. The average MC of pears was found to be 85 % $\pm$ 1.03 wet basis [22].

Osmotic dehydration

The osmotic solutions, which were in the range of 50–70 % (w/w) were prepared by mixing food grade sucrose with the necessary amount of distilled water according to the experimental design. Each experimental group was formed by four cylinders which were weighed individually. Pear cylinders were immersed in the osmotic solution in 1 l beakers and solution was agitated continuously with a magnetic stirrer. The process temperature was monitored using a thermocouple and a heating plate. For each experiment, the ratio of sample to osmotic solution and the agitation speed was maintained constant at 1:20 (w/w) and 300 rpm, respectively. Agitation was necessary to improve mass transfer and prevent the formation of a dilute solution film around the samples. In addition, it makes a uniform concentration and temperature profile inside the solution. A high ratio of sample to osmotic solution was made to avoid significant dilution of the medium by water removal, which would lead to local reduction of the osmotic driving force during the process. After specified immersion times, the osmotically dehydrated samples were taken out from the osmotic solutions and quickly rinsed with water to remove surplus solution adhering to the surfaces, gently blotted dry with absorbing paper in order to remove free water present on the surface for posterior weight. The weight and MC data of each sample were determined in order to calculate the response variables water loss (WL), sugar gain (SG) and weight reduction (WR), according to the following equations [23, 24]:

$$WL = \frac{m_i z_i - m_f z_f}{m_i} \times 100 \ (\mathrm{g}/100\,\mathrm{g}\ \textit{of fresh sample}) \quad (1)$$

$$SG = \frac{m_f s_f - m_i s_i}{m_i} \times 100 \ (\mathrm{g}/100\,\mathrm{g}\ \textit{of fresh sample}) \quad (2)$$

$$WR = WL - SG\,(g/100g\ \textit{of fresh sample}) \quad (3)$$

where m_i and m_f are the initial and final weight (g) of the samples, respectively; z_i and z_f are the initial and final mass fraction of water (g water/g sample), respectively; s_i and s_f are the initial and final mass fraction of total solids (g total solids/g sample), respectively. All experiments were performed in triplicate.

Vacuum drying

A laboratory scale vacuum dryer was designed and fabricated in the Department of Agricultural Machinery,

Ferdowsi University of Mashhad, Iran (Fig. 1). The dryer consisted of drying chamber, insulated carefully with rock wool, with an inner dimension of 30 × 30 × 30 cm^3, heating section, temperature control section, vacuum section, weighing section and moisture control section. The heating section was composed of two electric heaters at the sidewalls of drying chamber that heated by means of electric energy. Temperature control section consisted of thermostat type temperature controller (Model TZN4S, Autonics, South Korea), single-phase power controller (Model SPCI-35, Autonics, South Korea) and a thermocouple for controlling the drying chamber temperature. A vacuum pump (Model DV-142N-250, JB Industries, USA) and digital multi panel meter were main parts of vacuum section. Weighing section consisted of a load cell (Model UMI, DACELL, South Korea) and a digital indicator (Model DN-10W, DACELL, South Korea). Moisture in drying chamber was controlled by a humidity controller (Model Fox 1H, Dae Sung ENG, South Korea). The drying chamber was preheated for 2 h before the experiments started to obtain stable drying temperature. The pear slices pretreated with osmotic dehydration were spread in a single layer on the tray and drying experiments were conducted in the drying chamber at temperatures 50, 60 and 70 °C, respectively; and the vacuum pressures were 10, 20 and 30 kPa, respectively. Experiments were conducted with three replication and the average values were used for analysis.

Determination of shrinkage, moisture content, and rehydration ratio

Moisture content of dried pears was determined by an oven drying method [22]. The samples of dried pears (5 g) were placed in a convection oven and dried at 105 °C for 24 h. The MC of dried pears was expressed in percentage on a wet basis [4].

Shrinkage (Sh) was determined from changes in volume of pear samples. Volume was determined using the liquid displacement method. Toluene was used instead of water because it caused the reduction of liquid absorption into pear. Shrinkage was calculated as (Eq. 4) [25]:

$$Sh = \frac{V_0 - V}{V_0} \times 100 \tag{4}$$

where V_0 and V are initial (prior to osmotic dehydration) and final (after vacuum drying) volume of pear, respectively.

Rehydration ratio (RR), a measure of rehydration characteristics of dried pear, was determined by soaking known weight (5–10 g) of sample in sufficient volume of water in a glass beaker (approximately 30 times of weight of dried pears) at 95 °C for 20 min. Subsequently, the rehydrated samples were drained, excess water removed using absorbent paper and weighed. RR was calculated using Eq. 5 [24]:

$$RR = \frac{W_r}{W_d} \tag{5}$$

where, W_r is the drained weight of rehydrated sample (g) and W_d is the weight of dried sample used for rehydration (g).

Experimental design and statistical analysis

At the first stage, RSM was used to estimate the main effects of osmotic dehydration process on WL, solid gain (SG) and WR in pear slices. A face centered central composite design (FCC) [26] was used with sucrose concentration (50–70 %, w/w), temperature (25–55 °C) and immersion time (60–120 min) being the independent process variables (Table 1). This design requires three levels for each factor, thus making the total number of experiments equal to 20 instead of 27 with full factorial design (Table 2).

The levels of the input variables in coded and actual form are given in Table 1. The response functions (Y) were WL (Y_1), SG (Y_2), and WR (Y_3). These values were related to the coded variables (X_i, $i = 1$, 2 and 3) by a second-degree polynomial using the equation below:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_2^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \varepsilon \tag{6}$$

where Y is a response, X_is are the coded independent variables, and βs are regression coefficients. Statistical significance of the terms in the regression equations was examined. Regression analysis and analysis of variance (ANOVA) were conducted for fitting the models represented by Eq. 6 and to examine the statistical significance of the model terms. The adequacy of the models were determined using model analysis, lack-of fit test and R^2 (coefficient of determination) analysis. The three-dimensional plots were drawn by keeping one variable constant at the center point and varying the other two variables within the experimental range. Optimal conditions for the osmotic dehydration of pear depended on sugar concentration, temperature and immersion time were obtained using the predictive equations of RSM.

The same methodology was utilized to estimate the main effects of vacuum drying process on MC, RR, and Sh as quality attributes of a dried product. Table 3 shows the independent variables used to determine the optimum vacuum drying of osmotic pretreated pear slices including the coded and un-coded form (actual units). The independent variables affecting the quality of the end product

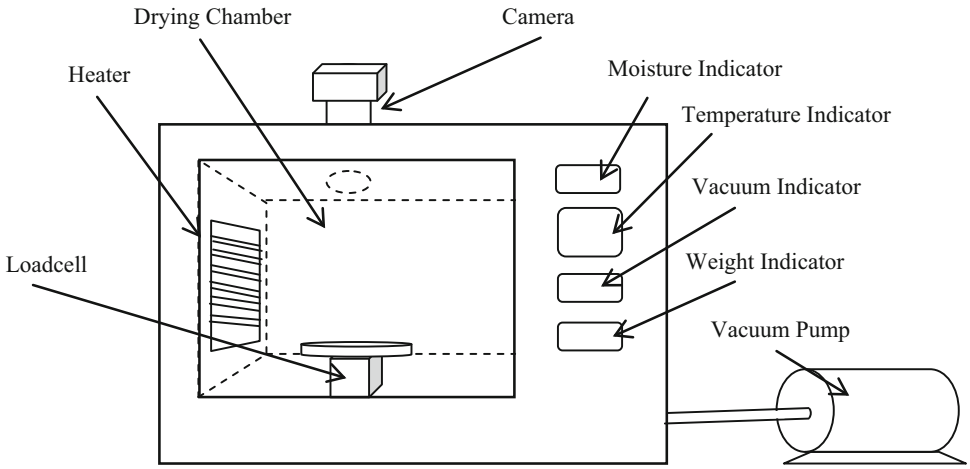

Fig. 1 Schematic diagram of vacuum drying system

Table 1 The levels of different process variables in coded and uncoded forms for osmotic dehydration

Variables	Symbol	Unit	Coded values		
			−1	0	+1
Temperature	X_1	°C	25	40	55
Concentration	X_2	% (w/w)	50	60	70
Time	X_3	min	60	90	120

during vacuum drying were the vacuum pressure (10–30 kPa), drying temperature (50–70 °C), and the drying time (180–300 min) of the product. The levels of independent variables were selected on the basis of preliminary experiments. Experiments were conducted according to second-order face-centered central composite design [27] with three levels of each variable (Table 4). In both stages, experiments were randomized in order to minimize the effects of unexplained variability in the

Table 2 Face centered central composite design and observed values of response variables for osmotic dehydration process

Run no.	Temperature (°C)	Concentration (%, w/w)	Time (min)	Water loss (%)	Solid gain (%)	Weight reduction (%)
1	25	50	60	5.30	2.01	3.29
2	55	50	60	18.28	3.17	15.11
3	25	70	60	7.26	3.14	4.12
4	55	70	60	20.28	5.03	15.25
5	25	50	120	8.32	2.86	5.46
6	55	50	120	25.78	6.44	19.34
7	25	70	120	10.71	4.72	6.00
8	55	70	120	32.87	7.14	25.74
9	25	60	90	8.11	3.25	4.86
10	55	60	90	23.17	7.61	15.57
11	40	50	90	10.82	3.17	7.65
12	40	70	90	15.66	5.68	9.98
13	40	60	60	11.22	4.31	6.90
14	40	60	120	14.82	5.36	9.45
15	40	60	90	11.58	4.87	6.71
16	40	60	90	13.63	5.13	8.50
17	40	60	90	15.01	5.01	10.00
18	40	60	90	13.49	4.36	9.13
19	40	60	90	14.84	6.40	8.44
20	40	60	90	14.34	5.08	9.26

Table 3 The levels of different process variables in coded and uncoded forms for vacuum drying

Variables	Symbol	Unit	Coded values		
			−1	0	+1
Vacuum pressure	X_1	kPa	30	20	10
Temperature	X_2	°C	50	60	70
Time	X_3	min	180	240	300

observed responses due to extraneous factors. RSM was applied to various observed responses using a statistical software package Design-Expert version 6.02 (Stat ease Inc., Minneapolis, USA).

Finally, validation tests were performed to determine the suitability of the model equations for prediction of the optimum response variables. This is performed because a fractional factorial design was used as the experimental design [19].

Results and discussion

The design and results of experiments was shown in Tables 2 and 4. Multiple linear regression analysis of the experimental data yielded second order polynomial models for predicting WL, SG, WR, MC, RR and Sh. ANOVA was used to assess the effect of variables on the responses. Regression equation coefficients of the proposed models and statistical significance of all main effects calculated for each response were obtained and effects being not significant ($p > 0.05$) were stepped down from models without damaging the model hierarchy (Tables 5, 6). The coefficient of determination, R^2, was found to be higher than 0.8 for all the responses. Analysis of variance indicated that the models are highly significant ($p < 0.0001$) for all the responses. The results of ANOVA also showed that the lack of fit was not significant for all response surface models at 95 % confidence level. To visualize the combined effects of two variables on any response, the three-dimensional plots of the response surfaces were generated for each of fitted models as the function of two independent variables, while keeping the other variable at the central value. Six different response surface plots (Figs. 2, 3, 4, 5, 6 and 7) were illustrated by maintaining one of factors constant for each figure. These figures were typical examples plotted for center points of constant factor. Effects of variables on responses were discussed by evaluation of these plots.

Water loss

Table 5 indicates that all linear terms of process variables have significant effect ($p < 0.05$) on WL. Furthermore,

Table 4 Face centered central composite design and observed values of response variables for vacuum drying process

Run no.	Vacuum pressure (kPa)	Temperature (°C)	Time (min)	Moisture content (%)	Rehydration ratio(g/g)	Shrinkage (%)
1	10	50	180	50.74	1.30	55.52
2	30	50	180	60.57	1.19	55.60
3	10	70	180	36.88	1.48	65.49
4	30	70	180	54.26	1.25	60.03
5	10	50	300	28.17	1.45	69.00
6	30	50	300	55.33	1.24	58.84
7	10	70	300	11.58	1.62	78.66
8	30	70	300	35.06	1.50	78.29
9	10	60	240	12.47	1.51	70.73
10	30	60	240	45.75	1.27	63.28
11	20	50	240	52.02	1.26	59.74
12	20	70	240	37.17	1.46	74.15
13	20	60	180	60.95	1.18	64.54
14	20	60	300	41.51	1.47	71.81
15	20	60	240	52.62	1.28	67.59
16	20	60	240	53.27	1.33	64.20
17	20	60	240	43.22	1.35	72.96
18	20	60	240	48.46	1.34	63.68
19	20	60	240	50.93	1.33	70.30
20	20	60	240	43.85	1.31	67.77

Table 5 Anova evaluation of linear, quadratic, and interaction terms for each response variable and coefficient of prediction models

Source	DF	Water Loss (%)			DF	Solid gain (%)			DF	Weigh reduction (%)		
		Coefficient	SS	p value[a]		Coefficient	SS	p value		Coefficient	SS	p value
Model	5	13.54	829.14	< 0.0001	4	5.14	35.51	< 0.0001	5	8.60	564.06	< 0.0001
X_1	1	8.07	651.04	< 0.0001	1	1.34	17.97	< 0.0001	1	6.73	452.69	< 0.0001
X_2	1	1.83	33.43	0.0006	1	0.81	6.49	0.0018	1	1.02	10.47	0.0456
X_3	1	3.02	91.01	< 0.0001	1	0.88	7.82	0.0009	1	2.13	45.47	0.0004
X_1^2	1	2.47	30.45	0.0009					1	2.87	41.19	0.0007
X_2^2					1	−0.80	3.23	0.0177				
X_3^2												
$X_1\ X_2$												
$X_1\ X_3$	1	1.70	23.22	0.0025					1	1.33	14.25	0.0227
$X_2\ X_3$												
Residual	14		24.03		15		6.83		14		30.43	
Lack of fit[b]	9		16.12	0.4703	10		4.52	0.5435	9		24.18	
Pure error	5		7.91		5		2.30		5		6.25	
Total	19		853.17		19		42.33		19		594.48	
R^2		0.9718				0.8388				0.9488		
Adj-R^2		0.9618				0.7958				0.9305		
CV			8.87				14.24					14.69

[a] p value <0.05 is significant at $\alpha = 0.05$

[b] Lack of fit is not significant at p value >0.05

Table 6 ANOVA evaluation of linear, quadratic, and interaction terms for each response variable and coefficient of prediction models

Source	DF	Moisture content (%)			DF	Rehydration ratio (g/g)			DF	Shrinkage (%)		
		Coefficient	SS	p value[a]		Coefficient	SS	p value		Coefficient	SS	p value
Model	5	46.80	3232.35	< 0.0001	4	1.33	0.25	< 0.0001	3	66.61	697.05	< 0.0001
X_1	1	11.11	1234.53	< 0.0001	1	−0.092	0.085	< 0.0001	1	−2.34	54.59	0.0392
X_2	1	−7.19	516.79	0.0007	1	0.088	0.077	< 0.0001	1	5.79	335.37	< 0.0001
X_3	1	−9.18	842.08	< 0.0001	1	0.089	0.078	< 0.0001	1	5.54	307.08	< 0.0001
X_1^2	1	−14.12	637.85	0.0003	1	0.050	0.013	0.0159				
X_2^2												
X_3^2	1	8.00	204.81	0.0160								
$X_1\ X_2$												
$X_1\ X_3$												
$X_2\ X_3$												
Residual	14		382.37		15		0.026		16		173.22	
Lack of fit[b]	9		287.57	0.2953	10		0.023	0.0775	11		110.44	
Pure error	5		94.80		5		2.999×10^{-3}		5		62.78	
Total	19		3614.72		19		0.28		19		870.26	
R^2		0.8942				0.9080				0.8010		
Adj-R^2		0.8564				0.8835				0.7636		
CV			11.95				3.05					4.94

[a] p value <0.05 is significant at $\alpha = 0.05$

[b] Lack of fit is not significant at p value >0.05

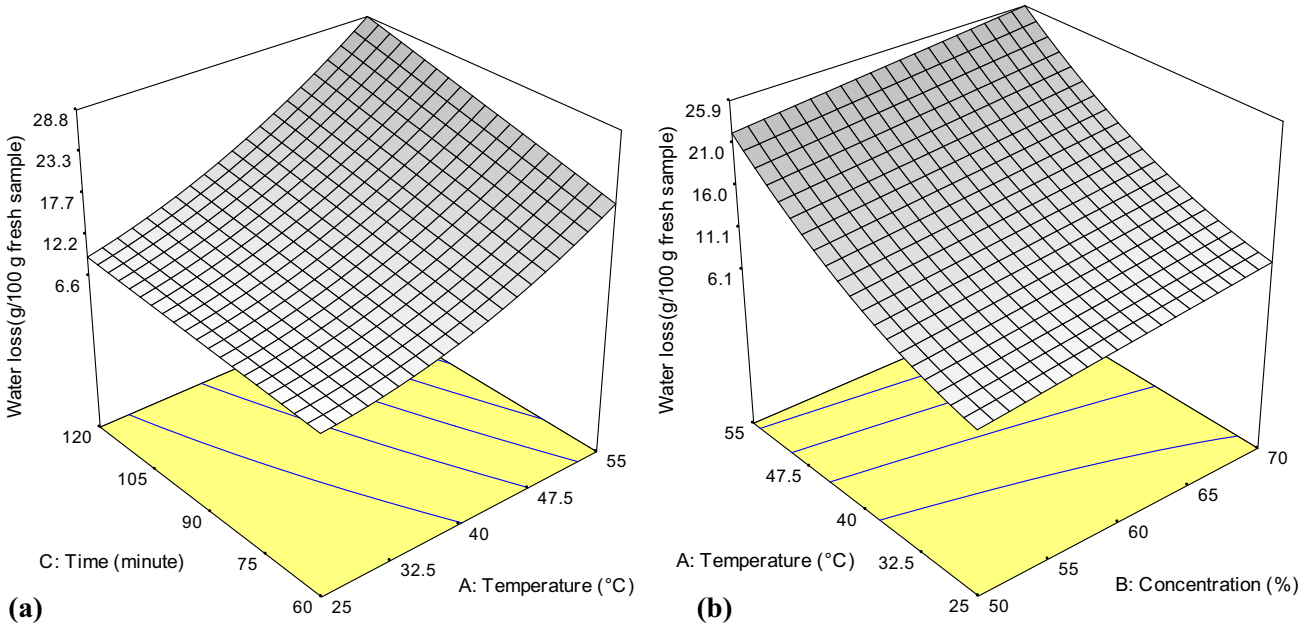

Fig. 2 Response surface and contour plots for water loss

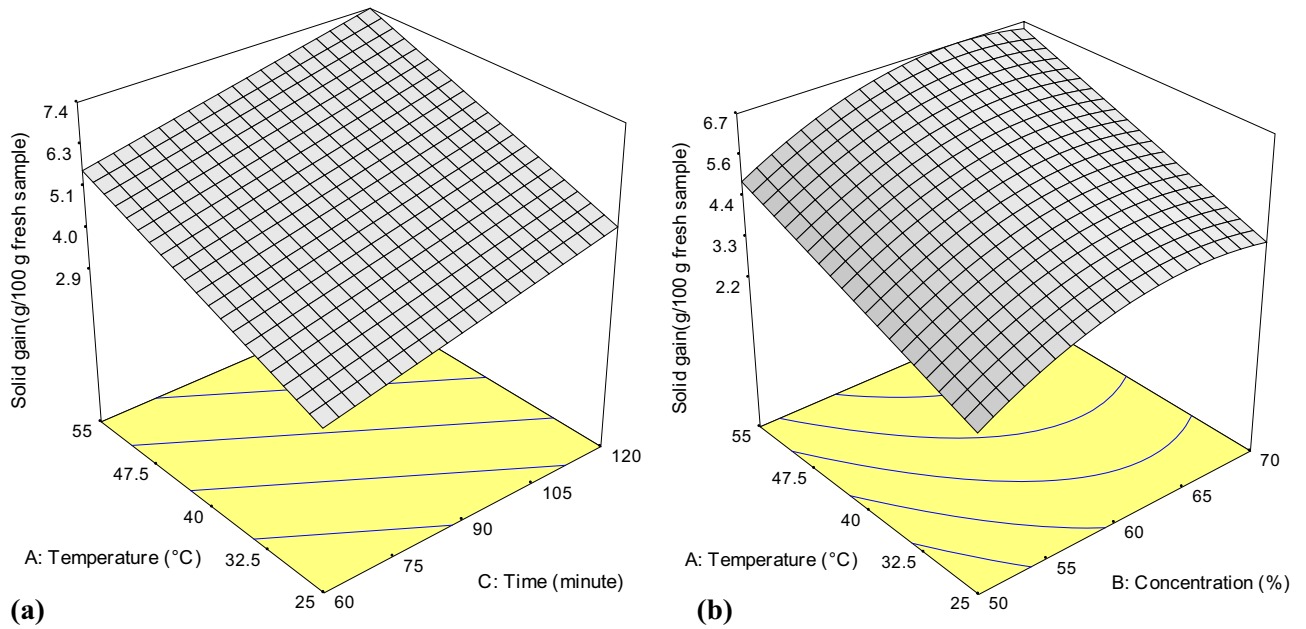

Fig. 3 Response surface and contour plots for solid gain

quadratic effect of temperature and interaction of 'temperature and time' have significant effects on WL during osmotic dehydration ($p < 0.05$). The magnitude β values indicates the maximum positive effect of temperature ($\beta = 8.07$) followed by immersion time ($\beta = 3.02$) and sucrose solution concentration ($\beta = 1.83$). These results indicate an increased WL with increase of temperature, immersion time, and sucrose solution concentration. Figure 2a reveals that increasing temperature with immersion time rises up WL rapidly. Especially, higher process temperatures seem to promote faster WL so that it reduced the time required to reach the equilibrium concentrations [28]. This interaction between time and temperature is in accordance with the results of variance analysis (Table 5). Figure 2b shows the increased WL with increase in sucrose solution concentration and temperature. These results are in agreement with [29] who also observed an increase in WL with increase in concentration of the osmotic agent and

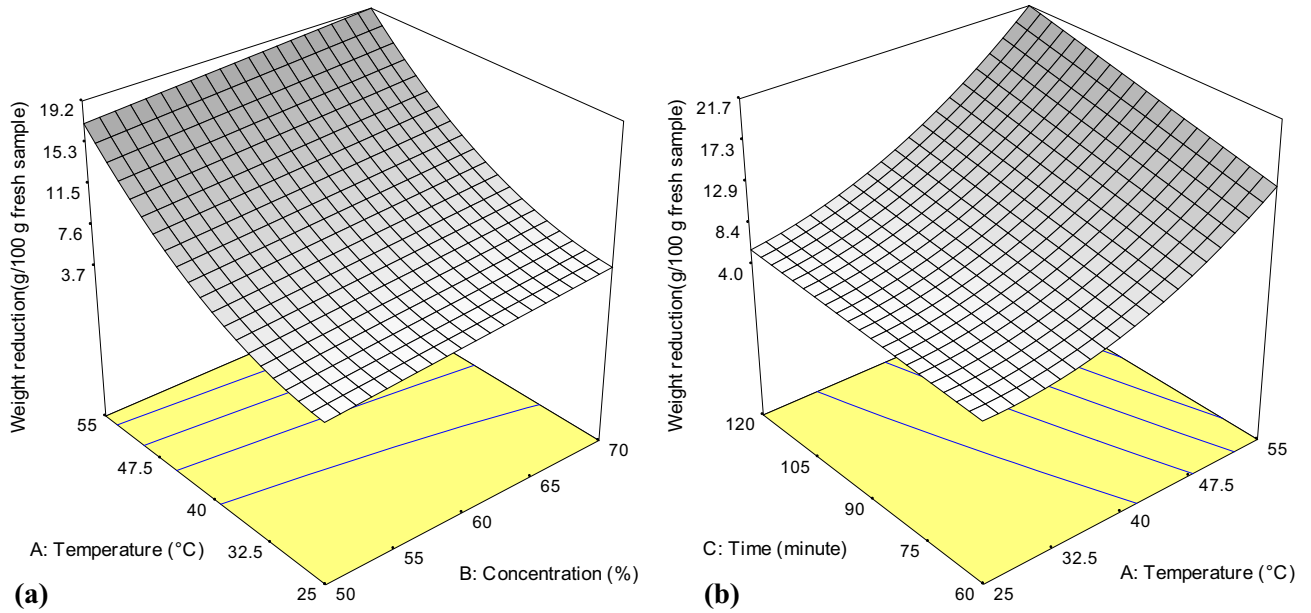

Fig. 4 Response surface and contour plots for weight reduction

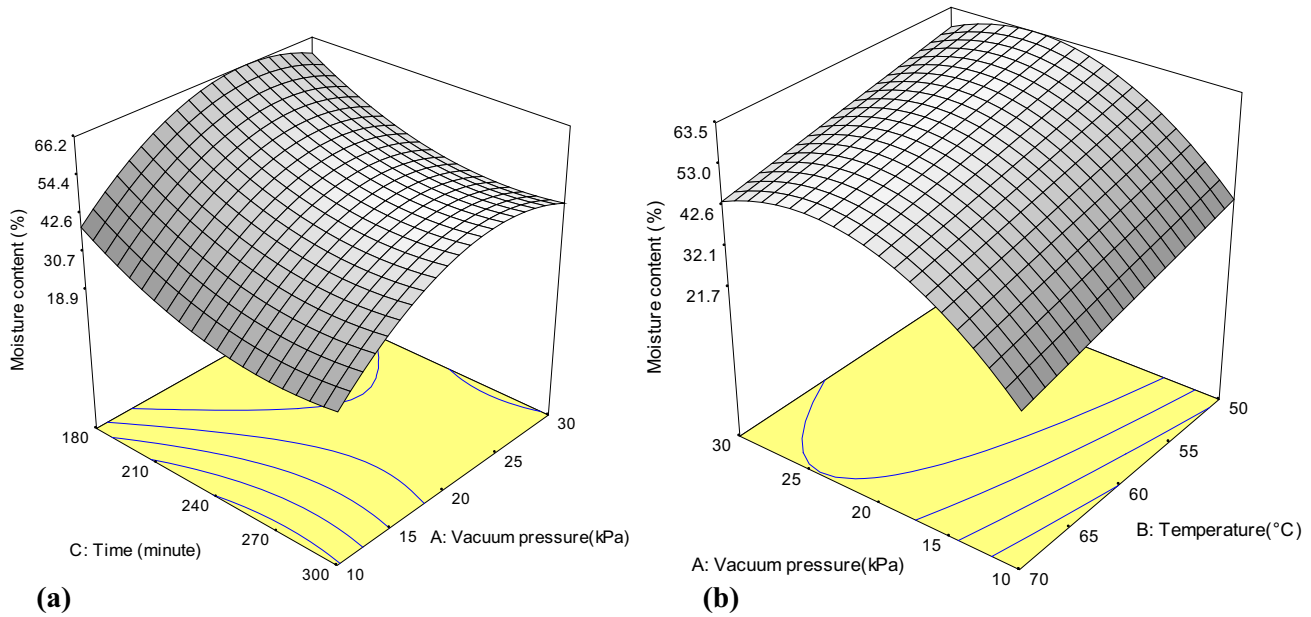

Fig. 5 Response surface and contour plots for moisture content

temperature. This might be due to the fact that the increase in temperature decreases the viscosity of the osmotic solution and thus reduces the external resistance to mass transfer at product surface to facilitate the outflow of water through cellular membrane. The increase in WL with osmotic solution concentration is mainly due to the increase in the osmotic pressure gradient [29]. The developed model, in the form of un-coded process variables (after neglecting non-significant terms at 5 % level of significance), is as follows:

$$WL = +3.17950 - 0.68018 \times \text{Temperature} + 0.18285 \times \text{Concentration} - 0.050866 \times \text{Time} + 0.010967 \times \text{Temperature}^2 + 3.78558 \times 10^{-3} \times \text{Temperature} \times \text{Time}$$

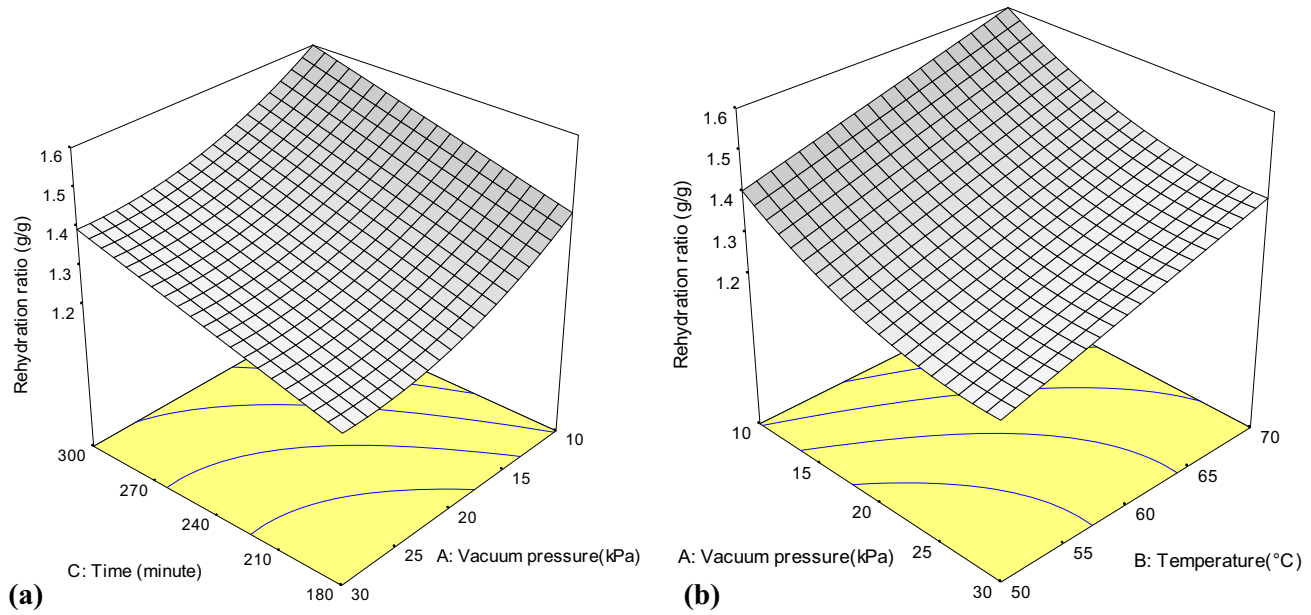

Fig. 6 Response surface and contour plots for rehydration ratio

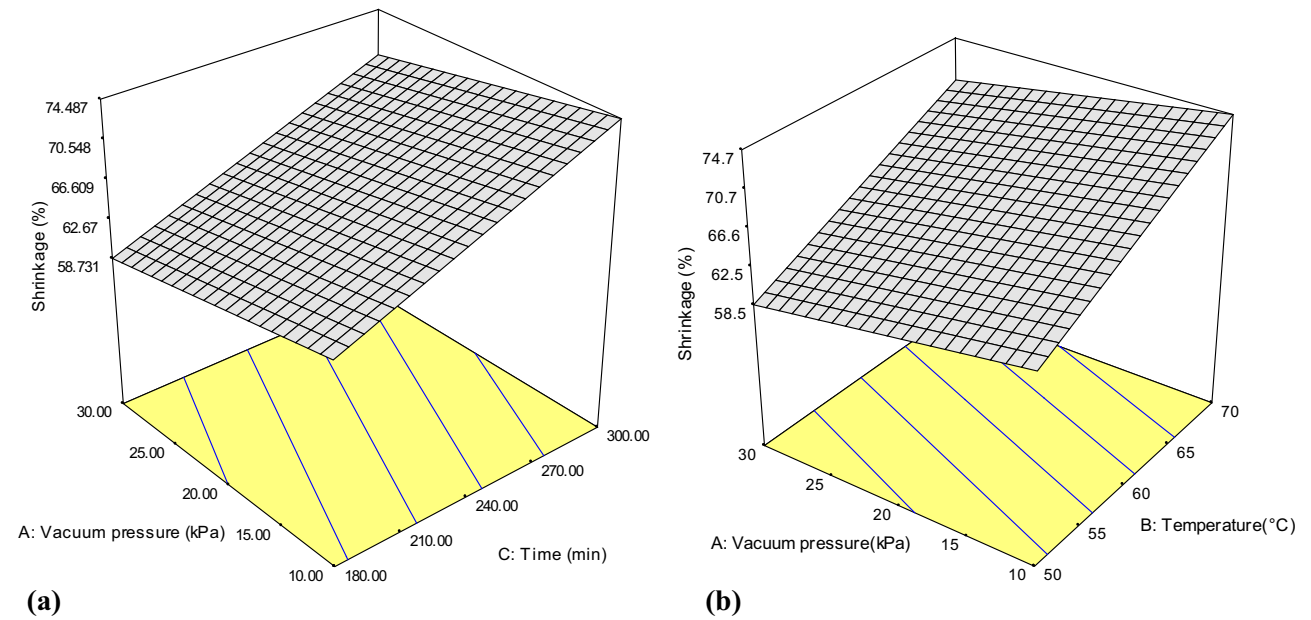

Fig. 7 Response surface and contour plots for shrinkage

Solid gain

As shown in Table 5, all the process variables at linear level have significant effects on SG ($p < 0.05$). Furthermore, the quadratic term of sucrose concentration has significant effect on solid gain during osmotic dehydration. The relative magnitude of the β-values indicates the maximum positive effect of temperature ($\beta = 1.34$), followed by immersion time ($\beta = 0.88$) and sucrose solution concentration ($\beta = 0.81$). Figure 3a indicates that solute gain increased with temperature might be because of decrease in viscosity of the osmotic solution resulting in high diffusion rates of solute. As shown in Fig. 3b, the solute gain increased with increase in osmotic solution concentration is mainly because of high concentration difference between the pear slices and osmotic solution [29]). The quadratic model developed in the un-coded form of process variables (at 5 % level of significance) is:

$$SG = -34.84640 + 0.089365 \times \text{Temperature} + 1.04469 \times \text{Concentration} + 0.029482 \times \text{Time} - 8.03449 \times 10^{-3} \times \text{Concentration}^2$$

Weight reduction

The p values (Table 3) indicate that all linear terms, quadratic term of temperature and interaction term of 'temperature and time' have significant effects ($p < 0.05$) on WR during osmotic dehydration. The temperature have the maximum positive effect ($\beta = 6.73$) followed by immersion time ($\beta = 2.13$) and sucrose solution concentration ($\beta = 1.02$) on WR. Figure 4a and b show increase in WR with increase in temperature, sucrose concentration and osmosis time. The following regression model in terms of un-coded factors was obtained for WR:

$$WR = +9.21257 - 0.83888 \times \text{Temperature} + 0.10230 \times \text{Concentration} - 0.047542 \times \text{Time} + 0.012757 \times \text{Temperature}^2 \times 2.96545 \times 10^{-3} \times \text{Temperature} \times \text{Time}$$

Optimization of osmotic dehydration pretreatment

The optimization of osmotic dehydration pretreatment was applied for selected ranges of temperature, sucrose solution concentration and immersion time as 25–55 °C, 50–70 % (w/w), and 60–120 min, respectively. The constraint criteria for optimization are shown in Table 7. Optimum conditions for osmotic dehydration of pears were determined to obtain the criteria; maximum WL and WR, and minimum solids gain. Second order polynomial models obtained in this study were utilized for each response in order to determine the specified optimum dehydration condition. These regression models were valid only in the selected experimental domain. So, optimization criteria were selected based on different parameters including economical and product-quality-related attributes [24, 28]. By applying desirability function method, solution was obtained for the optimum covering criteria as 55 °C for temperature, 50 % for sucrose solution concentration and 115 min for immersion time. At this point, WL, SG and WR were calculated as 26.01 (g/100 g of fresh sample), 5.59 (g/100 g of fresh sample) and 19.98 (g/100 g of fresh sample), respectively. Vacuum drying treatment was performed at optimized osmotic dehydration condition.

Moisture content

The experimental data of MC during vacuum drying of osmotic pretreated pear slices are presented in Table 4. An analysis of variance (ANOVA) of results shown in Table 6 indicates that all the process variables in vacuum drying-vacuum pressure, temperature and drying time-had significant linear effects ($p < 0.05$) on MC of dried pear slices. The results also showed that quadratic terms of vacuum pressure and drying time were significant at $p < 0.05$. Among all process variables, vacuum pressure has maximum effect on MC as indicated by regression coefficient. Figure 5a and b show the response surface plots of MC as a function of vacuum pressure, temperature, and drying time. These figures indicate decrease in MC with increase of vacuum pressure, temperature and time at process duration. Higher vacuum degree increases the driving force for mass transfer and facilitates the evaporation and volatilization of water from the materials [30]. Thus higher vacuum levels causes less MC in the product during drying process. In the case of the effects of temperature and drying time similar trend was reported for MC of olive leaves during hot air drying [20, 31]. The regression equation describing the effect of the process variables on MC of dried pear slices in terms of actual factors of the variables are given as:

$$MC = +175.94619 + 6.75843 \times \text{Vacuumpressure} - 0.71888 \times \text{Temperature} - 1.21963 \times \text{Time} - 0.14118 \times \text{Vacuum pressure}^2 + 2.22227 \times 10^{-3} \times \text{Time}^2$$

Rehydration ratio

From ANOVA (Table 4), it can be observed that linear terms of process variables (vacuum pressure, temperature

Table 7 Optimization criteria for different factors and responses

Factors/responses	Goal	Lower limit	Upper limit	Importance
Temperature (°C)	In range	25	55	3
Sucrose concentration (%)	In range	50	70	3
Time (min)	In range	60	120	3
Water loss (%)	Maximize	5.30	32.87	3
Solid gain (%)	Minimize	2.01	7.61	3
Weight reduction (%)	Maximize	3.29	25.74	3

Table 8 Optimization criteria for different factors and responses

Factors/responses	Goal	Lower lmit	Upper limit	Importance
Vacuum pressure (kPa)	In range	10	30	3
Temperature (°C)	In range	50	70	3
Time (min)	In range	180	300	3
Moisture content (%)	Minimize	11.58	60.95	3
Rehydration ratio (g/g)	Minimize	1.18	1.62	3
Shrinkage (%)	Minimize	55.52	78.66	3

Table 9 Predicted and experimental values for the responses at optimum conditions

Response variable	Predicted value	Experimental value
Osmotic dehydration pretreatment		
Water loss (%)	26.01	26.53 ± 2.36
Solid gain (%)	5.59	6.98 ± 0.72
Weight reduction (%)	19.98	19.54 ± 2.86
Vacuum drying		
Moisture content (%, wb)	23.26 %	25.24 ± 1.41
Rehydration ratio (g/g)	1.46	1.44 ± 0.04
Shrinkage (%)	67.45 %	69.32 ± 2.07

and drying time) and quadratic term of vacuum pressure significantly affected the RR at $p < 0.05$. It may be concluded that the RR depends mainly on vacuum pressure, as its linear as well as quadratic effects are significant. Figure 6a and b show the response surface plots of RR as a function of vacuum pressure, temperature and drying time, showing that increasing vacuum pressure and temperature leads to higher capability of water abortion of dried product means higher RR. Time of drying had similar effect to temperature that higher time of drying resulted higher RR. Rehydration ratio depends mainly on dried product micro structure, that rate of drying is a significant parameter for final products quality characteristics including RR and shrinkage. At lower pressure level, the RR increased, owing to the increased drying rate and creation of pores that are induced by vacuum conditions. Rehydration properties were improved by drying at lower system pressure and higher temperature as indicated by higher values of RR, similar results were obtained by Giri and Prasad [32] for RR of microwave-vacuum dried button mushroom. The regression model for RR relating the process variables is given as:

$$RR = +0.83571 - 0.029306 \times \text{Vacuumpressure} + 8.77450 \times 10^{-3} \times \text{Temperature} + 1.47628 \times 10^{-3} \times \text{Time} + 5.02182 \times 10^{-4} \times \text{Vacuumpressure}^2$$

Shrinkage

As shown in Table 4, all the process variables at linear level have significant effects on Shrinkage ($p < 0.05$). Figure 7a and b reveal an increase in shrinkage with increase of vacuum level, temperature and time at process duration. Chauhan and Srivastava [27] stated that linear shrinkage in dehydrated products primarily depends on MCs and drying rates during initial stages of drying. Thus, the higher Shrinkage can be attributed to higher drying rates and lower MCs of dried pear slices at higher vacuum levels and higher temperatures during vacuum drying process. The following regression equation, describing the effect of process variables on shrinkage ratio, was obtained:

$$Shrinkage = +14.36922 - 0.23365 \times \text{Vacuumpressure} + 0.57911 \times \text{Temperature} + 0.092358 \times \text{Time}$$

Optimization of vacuum drying

Numerical optimization technique was carried out in order to optimize the process variables of vacuum drying. The optimum condition for osmotic pretreated pear slices was determined to obtain minimum MC, maximum RR and minimum shrinkage, while vacuum pressure, temperature, drying time were kept in the ranges 10–30 kPa, 50–70 C, and 180–300 min respectively. The constraint criteria for optimization are shown in Table 8. Optimum values of process variables were: 10 kPa vacuum pressure, 55 °C temperature and 250 min drying time. Corresponding to these optimum conditions, the predicted value for MC was 23.26 %, 1.46 RR and 67.45 % Shrinkage.

The results of experimental and predicted values are shown in Table 9. The experimental values (mean of three replicates) were found to be close to the predicted values, suggesting that the regression models are in agreement with osmotic dehydration pretreatment and vacuum drying of pear slices.

Conclusion

Response surface methodology was useful in optimizing process parameters for osmotic dehydration as pretreatment and vacuum drying of pear slices in order to achieve optimum operating conditions to obtain maximum WL, WR, and RR and minimum solid gain, MC, and shrinkage in osmo-vacuum drying of pear slices. The second-order polynomial models for all the response variables were found to be statistically significant with high values of R^2 (>0.8). The optimum conditions for maximum WL and WR and minimum solid gain, were 55 °C for temperature, 50 % for sucrose solution concentration and 115 min for immersion time, in order to obtain WL of 26.01 (g/100 g of fresh sample), solid gain of 5.59 (g/100 g of fresh sample), and WR of 19.98 (g/100 g of fresh sample) and optimal conditions for maximum RR and minimum MC and shrinkage, were 10 kPa for vacuum pressure, 55 °C for temperature, and 250 min for drying time in order to obtain MC 23.26 %, RR of 1.46 and shrinkage of 67.45 %. Osmotic dehydration of pear could effectively be used as a pretreatment prior to vacuum drying to reduce energy costs and maintain the naturalness of the product.

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