Mass exchange evaluation during optimization of osmotic dehydration for Oyster mushrooms (*Pleurotus sajor-caju*) in salt-sugar solution

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Abstract: The objective of this study was to investigate the osmotic dehydration of Oyster mushrooms in salt-sugar solution at different solution concentrations, immersion times, temperatures and solution to fruit ratio to analyze the water loss, solute gain and weight reduction. Salt-sugar uptake and water transfer were quantitatively investigated during osmotic dehydration of Oyster mushrooms using response surface methodology. Experiments were conducted in a thermostatically controlled agitating incubator. With respect to water loss, solute gain and weight reduction both linear and quadratic effects of four process variables were found to be significant. For each response, second order polynomial models were developed using multiple linear regression analysis. ANOVA was performed to check the adequacy and accuracy of the fitted models. The response surfaces and contour maps showing the interaction of process variables were constructed. Applying desirability function method, the optimum operating conditions were found to be: solution temperature – 42.3° C, immersion time – 44.21 min, salt-sugar concentration – 15 %: 52.57° B and solution to fruit ratio 4.99:1. At these optimum values, water loss, solute gain and weight reduction was 41, 2.15 and 38.6 (g/100 g initial mass) respectively.

Keywords: Mushrooms, Optimization, Osmotic dehydration, Response surface methodology, Salt-sugar solution

INTRODUCTION

Edible mushrooms are fleshy and spore-bearing fruiting body of endowed fungi (mostly Basidiomycetes) that grow naturally on the trunks, roots and above ground on soil or on its food source, which mainly comprises of dead matter or waste material (Chang and Miles, 1992; Stamets, 2001). The production and consumption of mushrooms is increasing tremendously throughout the world due to greater awareness of their nutritive and medicinal attributes. They have been consumed and appreciated for their flavour, economical and ecological values besides medicinal properties from ancient times (Ares *et al.*, 2007).

The mushrooms are credited to be the third largest macro-fungus cultivated as food for industrial purposes worldwide. *Pleurotus* spp. are the second most cultivated edible mushrooms worldwide after *Agaricus bisporus* which constitute about 25 % of total world production of cultivated mushrooms (Sanchez, 2010). *Pleurotus sajor-caju* popularly known as "Dhingri" in India is endowed with high protein content (rich in all the essential amino acids) required for an adult. Approximately 25–35 % of total amino acids occur as free amino acids. They are also known to be excellent sources of riboflavin, niacin and patothenic acid. The mineral content in fresh mushrooms is higher than is found in many fresh vegetables and fruits (Bano *et al.*, 1981). *P. sajor-caju* has benefited with hypertensive

effects through its active ingredients (Alam *et al.*, 2008), and are also known to be useful decomposers of various agricultural wastes (Kuforiji and Fasidi, 2008). In-vivo studies also revealed that diet from Oyster mushroom effectively retarded the progression of hypercholesterolemia and accumulation of cholesterol in liver (Bobek *et al.*, 1997). However, shelf-life of fresh mushrooms is very limited and starts deteriorating soon after the harvest. This quick deterioration is mainly caused by high metabolic activity, respiration rate, dehydration, microbial and enzymatic activities (Ares *et al.*, 2007). So, to explore the health benefits from mushrooms, there is necessity of post-harvest preservation like drying and dehydration.

Osmotic dehydration is a water removal process involving soaking foods, mostly fruits and vegetables in a hypertonic solution. Two major simultaneous counter-current flows occur during osmotic dehydration process; water flow out of the food into the solution and a simultaneous transfer of solute from the solution into the food (Madamba, 2003). Osmotic dehydration improves the sensorial and nutritional properties, preserve and improve the organoleptic properties of foods. Osmotic dehydration results in increased shelf-life. It is regarded as complementary treatment in food preservation technique in the processing of dehydrated foods, as it presents some of the benefits such as reducing the damage of heat to the flavour, colour as well as inhibits the browning by enzymes and reduces the energy costs compare to

other heat processing techniques (Torres *et al.*, 2006). Limited efforts have so far been made to process *P. sajorcaju* mushroom into dehydrated product. No attempt has been made to optimize the osmotic process parameters for osmo-cum-microwave dehydrated product of *P. sajorcaju* mushroom. The aim of the present study was to determine the effect of osmotic process parameters viz; solution temperature, salt-sugar concentration, duration of osmosis and solution to fruit ratio on water loss, solute gain and weight reduction and to optimize these parameters for developing higher quality finished dehydrated mushroom flakes.

MATERIALS AND METHODS

Experimental design and statistical analysis: Box-Behnken Design was used to design the experiments. The Response surface methodology (RSM) was applied to the experimental data using a commercial statistical package, Design-Expert trail version 8.0.7.1 (Statease Inc., Minneapolis, USA). RSM is an empirical statistical modeling technique employed for multiple regression analysis using quantitative data obtained from properly designed experiments to solve multivariate equations simultaneously (Prakash maran *et al.*, 2013). The process parameters (independent variables) selected for the optimization were immersion time (β_1), osmotic solution concentration (salt-sugar) (β_2), osmotic solution temperature (β_3) and solution to fruit ratio (β_4). The range of each independent variable was; β_1: 15-240 min, β_2: 15 %:45-65 ° B, β_3: 30-60° C and β_4: 4:1-8:1. The effects of the variables were studied on water loss (WL), solute gain (SG) and weight reduction (WR) of the slices during osmotic process. The variables were standardized for ease in computation and to reduce their relative effect on the responses. The number of experiments (N) required for the development of Box-Behnken Design is defined as $N = 2k (k - 1) + C_o$ (where k is number of factors and C_o is the number of central point). The design included 29 experiments with 5 central points. The following polynomial model was fitted to the data:

$$Y = b_0 + b_1\beta_1 + b_2\beta_2 + b_3\beta_3 + b_4\beta_4 + b_{12}\beta_{12} + b_{13}\beta_{13} + b_{14}\beta_{14} + b_{23}\beta_{23} + b_{24}\beta_{24} + b_{34}\beta_{34} + b_{11}\beta_1^2 + b_{22}\beta_2^2 + b_{33}\beta_3^2 + b_{44}\beta_4^2 \qquad (1)$$

Where, b_n are constant regression coefficients; Y is the response (i.e. WL, SG and WR); β_1, β_2, β_3 and β_4 are immersion time, salt-sugar concentration, temperature and STFR respectively. Statistical significance of the terms in the regression equations was examined. Response surface plots were generated with the same software.

Raw materials: Oyster mushrooms (*P. sajor-caju*) were used for the experimental studies. Fully matured mushrooms of commercial grade were procured from Mushroom Research Farm, Punjab Agricultural University, Ludhiana, India. The average moisture content of the mushrooms was found to be 90.3 % on a wet

basis initially. The mushrooms were cut into slices and were pre-treated using anti-microbial agent (Citric acid @ 40g/l) to avoid enzymatic browning (Brennan and Gormely, 2000). The commercial TATA salt and sugar was purchased from a local supermarket and were considered as an osmotic agents for osmotic study, for being cheap and easy availability.

Experimental procedure: The osmotic dehydration study was conducted in glass beakers, which were placed in a thermostatically controlled shaking incubator. For each experiment, known weights of mushroom was taken in a glass beakers containing calculated volumes of osmotic solution (STFR) of different salt-sugar concentrations and were placed inside a temperature and agitation controlled incubator. At each sampling time ranging from 15–240 min, the mushroom slices were taken out and then gently blotted with soft adsorbent paper and weighed and the effect of temperature was investigated. In each of the experiments fresh osmotic salt-sugar syrup was used. All the experiments were done in duplicates and the average value was taken for calculations. Agitation was necessary to improve the mass transfer to maintain uniform concentration, temperature profile and to prevent the formation of a dilute solution film around the samples. For each experiment a constant agitation speed of 150 rpm was maintained. Analysis for each sample was carried out; from which WL, SG and WR data were obtained. Net loss of water and solute gain after osmotic dehydration was calculated using the relationship:

$$\textbf{WL} = WR + SG \qquad (2)$$
$$\textbf{SG} = (m - m_o)/M_o \qquad (3)$$
$$\textbf{WR} = (M_o - M)/M_o \qquad (4)$$

Where, M_0 - initial mass of sample (g), M - mass of sample after dehydration (g), m_0 - initial mass of the solids in sample (g), m - mass of the solids in sample after dehydration (g).

RESULTS AND DISCUSSION

RSM modeling and effect of process variables on responses: According to the Box-Behnken Design, experiments were performed in order to find out the optimum combination of process parameters and to study their effects on WL, SG and WR for the osmotic dehydration of mushrooms. A model 'F-value' denotes 'F-statistic' and is the ratio of treatment mean sum of squares to the error mean sum of squares. F-value should be always higher as it represents the significance of the model. Lesser the value of F-value, it represents least significant/non-significant or more error in the model. F-value and p-value are inter-related. From the table values of process variables, it can be noticed that as F-value increases p-value decreases, hence represents more significance. A Model F-value of 11.507, 26.668 and 8.199 for WL, SG and WR respectively implies that the model is significant (P < 0.01). The 'lack of Fit F-value' of 1.612, 0.323 and 1.476 for WL, SG and WR was not

Table 1. ANOVA for water loss during osmotic dehydration of Oyster mushroom.

| Source | R^2 | Water loss | | |
		Sum of squares	F-value	p-value
Model	43.588	451.179	11.507	< 0.0001
β_1- Immersion time	2.035	49.714	17.751	0.001
β_2- Salt-Sugar	0.532	3.396	1.212	0.289
β_3-Temp.	5.240	329.473	117.640	< 0.0001
β_4-STFR	0.398	1.901	0.679	0.424
β_{12}	-0.222	0.197	0.070	0.795
β_{13}	0.192	0.147	0.052	0.822
β_{14}	0.077	0.024	0.008	0.928
β_{23}	0.069	0.019	0.007	0.936
β_{24}	0.206	0.169	0.060	0.809
β_{34}	0.021	0.002	0.001	0.980
β_1^2	-1.739	19.611	7.002	0.019
β_2^2	-0.376	0.916	0.327	0.577
β_3^2	-2.903	54.669	19.520	0.001
β_4^2	-0.304	0.599	0.214	0.651
Lack of Fit		1.612		
R^2		0.92		
Adj. R^2		0.84		
Pred. R^2		0.861		
CV (%)		4.044		
Adeq Precision		12.089		

Table 2. ANOVA for solute gain during osmotic dehydration of Oyster mushroom.

| Source | R^2 | Solute gain | | |
		Sum of squares	F-value	p-value
Model	2.724	12.624	26.668	< 0.0001
β_1- Immersion time	0.448	2.410	71.272	< 0.0001
β_2- Salt-Sugar	0.320	1.228	36.312	< 0.0001
β_3-Temp.	0.746	6.672	197.325	< 0.0001
β_4-STFR	0.262	0.821	24.280	0.0002
β_{12}	-0.005	0.000	0.003	0.959
β_{13}	-0.192	0.147	4.339	0.056
β_{14}	0.007	0.000	0.005	0.944
β_{23}	0.025	0.003	0.075	0.788
β_{24}	0.026	0.003	0.082	0.779
β_{34}	0.077	0.024	0.700	0.417
β_1^2	0.042	0.011	0.335	0.572
β_2^2	0.119	0.092	2.720	0.121
β_3^2	-0.393	0.999	29.555	< 0.0001
β_4^2	0.017	0.002	0.053	0.822
Lack of Fit		0.323		
R^2		0.964		
Adj. R^2		0.927		
Pred. R^2		0.84		
CV (%)		6.979		
Adeq Precision		20.114		

significant which indicated that the model was adequate for predicting the response.

Moreover the predicted R^2 values for WL, SG and WR of 0.861, 0.84 and 0.813 were in reasonable agreement with adjusted R^2 of 0.84, 0.927 and 0.782. The independent process parameters β_1, β_2, β_3 and β_4 were optimized for maximum WL and minimum SG. An analysis of variance was conducted to determine the significant effects of process variables on each response. Tables 1, 2 and 3 show that all the process variables were statistically significant for WL, SG and WR ($p < 0.05$). Coefficient of determination R^2 and adj -R^2 were calculated to check the adequacy and fitness of the model. The adjusted R^2 value corrects the R^2 value for the sample size and for the number of terms in the model. The values of R^2 were calculated to be 0.92, 0.964 and 0.891 for WL, SG and WR respectively which signifies the compatibility of the experimental data. The R^2 value was always between 0 and 1, and a value > 0.75 indicated aptness of the model. For a good statistical model, R^2 value should be close to 1.0. These higher values also signify the high significance of the model. If there are many terms in the model and the sample size is not very large, the adjusted R^2 may be noticeably smaller than the R^2. Here in this case also, it can be noticed adjusted R^2 value are lesser than the R^2. The closer values of R^2 and adj. R^2 obtained in the study explicates that the predicted values are in good agreement with the experimental values.

Higher values of coefficient of determination obtained for response variables indicated that the developed model for WL, SG and WR accounted for and adequately explained 92, 96.4 and 89.1 percent of the total variation. The coefficient of variation (CV %) indicates the relative dispersion of the experimental points from the predictions of the second-order polynomial models (Prakash maran *et al.,* 2013). The values of CV are low as 4.044, 6.979 and 4.39 for WL, SG and WR, which indicate that the deviations between experimental and predicted values are low. The values of Adeq Precision are 12.089, 20.114 and 9.943 for WL, SG and WR. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. In this work, the ratio is found to be > 9 which indicates an adequate signal. The comparative effect of each factor on WL, SG and WR was observed by the F-values in the ANOVA (Tables 1-3) and also by the magnitudes of coefficients of the coded variables. The F-values indicated that solution temperature and immersion time were the most influencing factors followed by salt-sugar concentration and STFR was least effective over WL, SG and WR.

It was reported that above 60 % sugar concentration, additional increase in sugar concentration did not promote further water loss in fruits and vegetables (Ponting *et al.,* 1966). Therefore, 65 % sugar was chosen as the upper limit for the salt-sugar concentration in this study. The effect of β_1, β_2, β_3 and β_4 on the WL is given in fig.1. The WL is increased with temperature especially in the early stages of the immersion, after which the rate of WL from mushrooms into the solution gradually slowed down

Table 3. ANOVA for weight reduction during osmotic dehydration of Oyster mushroom.

| Source | R^2 | Weight reduction | | |
		Sum of squares	F-value	p-value
Model	41.065	332.099	8.199	0.0002
β_1- Immersion time	1.587	30.233	10.450	0.006
β_2- Salt-Sugar	0.212	0.540	0.187	0.672
β_3-Temperature	4.494	242.374	83.778	< 0.0001
β_4-STFR	0.137	0.224	0.077	0.785
β_{12}	-0.217	0.188	0.065	0.802
β_{13}	0.383	0.587	0.203	0.659
β_{14}	0.070	0.020	0.007	0.935
β_{23}	0.043	0.008	0.003	0.960
β_{24}	0.179	0.129	0.044	0.836
β_{34}	-0.056	0.012	0.004	0.949
β_1^2	-1.881	22.940	7.929	0.014
β_2^2	-0.595	2.295	0.793	0.388
β_3^2	-2.611	44.208	15.281	0.002
β_4^2	-0.421	1.147	0.397	0.539
Lack of Fit		1.476		
R^2		0.891		
Adj. R^2		0.782		
Pred. R^2		0.813		
CV (%)		4.39		
Adeq Precision		9.943		

with time towards equilibrium end point. On the other hand, the WL increased gradually with salt-sugar concentration over the entire osmotic dehydration process. Higher temperatures seem to promote faster water loss through swelling and plasticising 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). Rapid removal of water in early stages with increasing temperatures of osmosis has been reported for mushrooms (Kar and Gupta, 2001; Murumkar *et al.*, 2007), green pumpkins (Chang *et al.*, 2003), potatoes (Eren and Kaymak-Ertekin, 2006), litchi (Vishal *et al.*, 2009) and papaya (Jain *et al.*, 2011). So, initial stages of osmotic dehydration is the most important one, since the transport phenomena are faster and they have a dramatic impact on further evolution of the osmotic process (Hawkes and Flink, 1978; Conway *et al.,* 1983; Biswal *et al.,* 1991). The effect of β_1, β_2, β_3 and β_4 on the SG is given in fig.2. The SG increases sharply with immersion time and temperature. This can be attributed to the increased mass transfer of sugar molecules due to possible membrane swelling or plasticizing effect which might increase the cell membrane permeability to sucrose molecules (Lazerides *et al.*, 1997). The effect of β_1, β_2, β_3 and β_4 on the WR is given in fig. 3. WR mainly depends upon WL and SG during osmotic dehydration process.

An empirical model for the best response was obtained through RSM. The mathematical expressions of
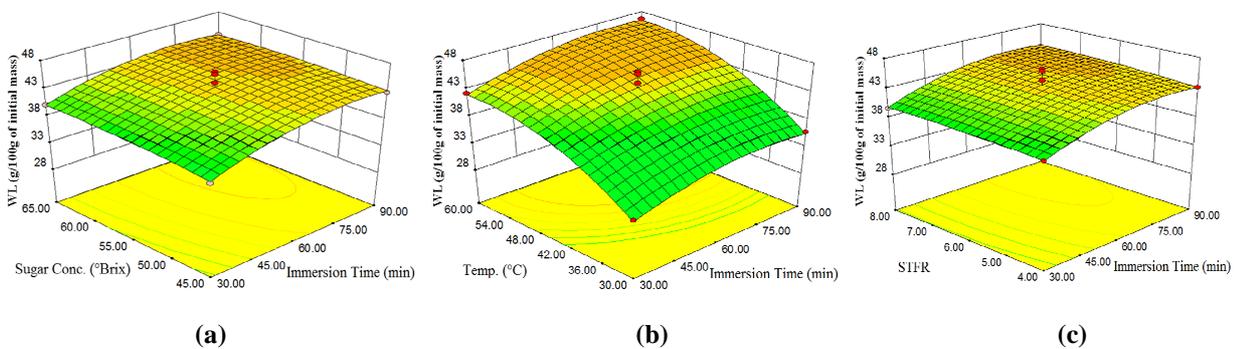
Fig. 1. *WL during osmotic dehydration of mushroom as a function of : (a) sugar concentration and immersion time (b) solution temperature and immersion time (c) STFR and immersion time.*
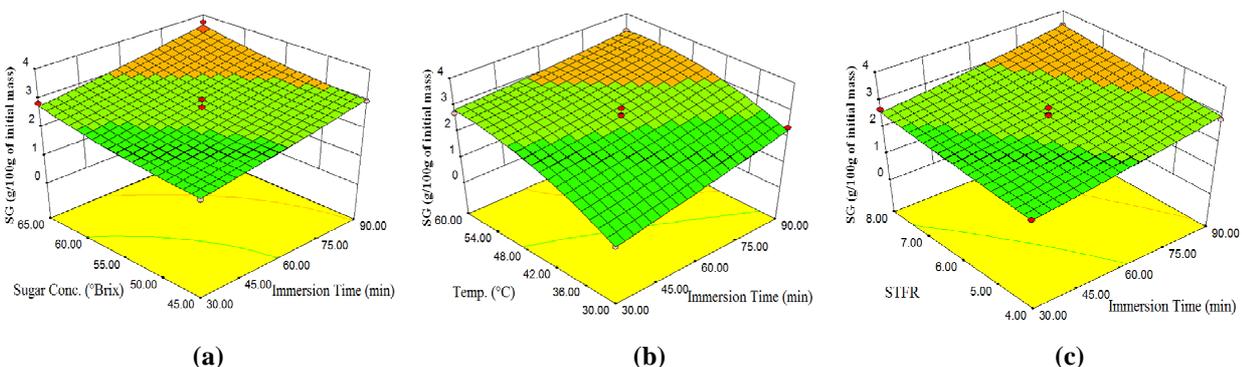
Fig. 2. *SG during osmotic dehydration of mushroom as a function of: (a) sugar concentration and immersion time (b) solution temperature and immersion time (c) STFR and immersion time.*
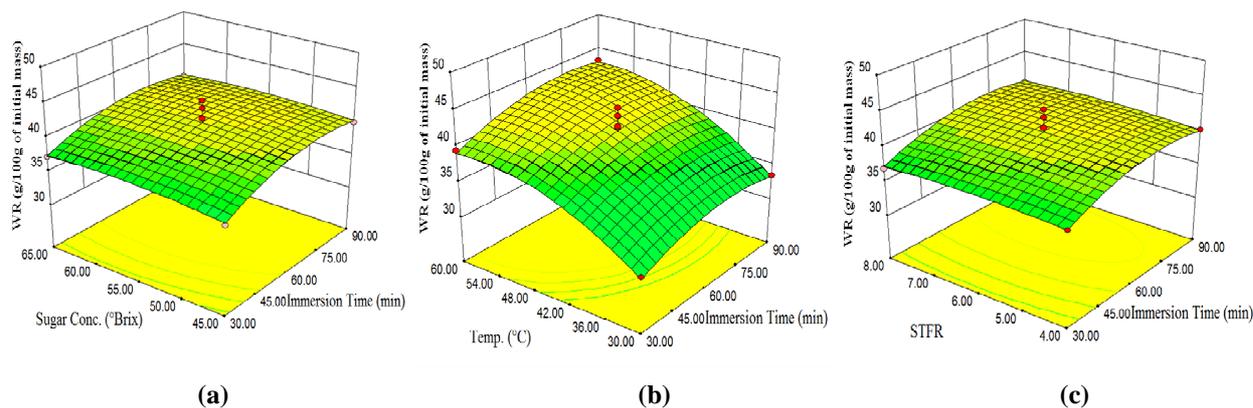
Fig. 3. *WR during osmotic dehydration of mushroom as a function of: (a) sugar concentration and immersion time (b) solution temperature and immersion time (c) STFR and immersion time.*
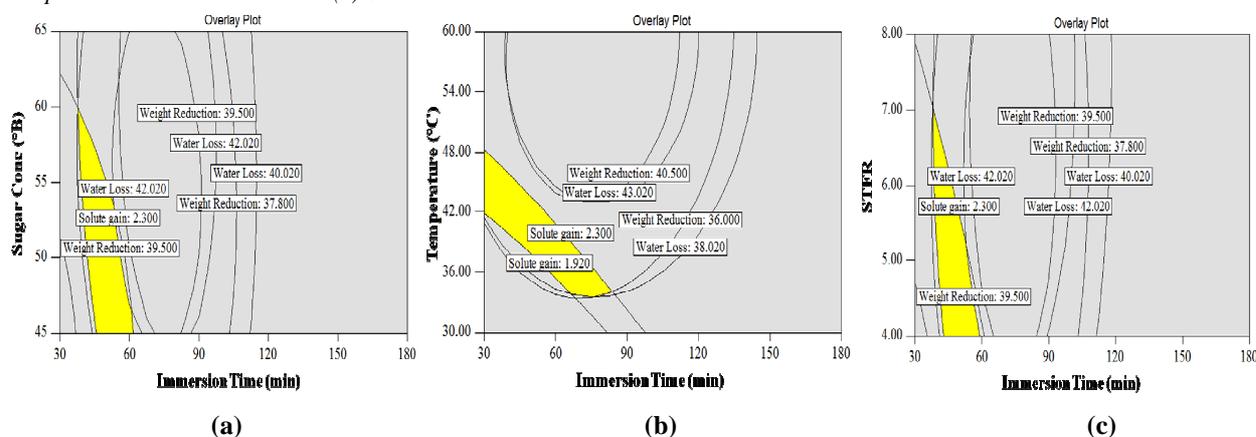
Fig. 4. *Superimposed contour plots of different responses for optimization of osmotic dehydration of mushroom as function of: (a) sugar concentration and immersion time (b) solution temperature and immersion time (c) STFR and immersion time.*

relationship describing the effects of process variables to the response are shown below:

$WL = 43.59 + 2.04 \beta_1 + 0.53 \beta_2 + 5.24 \beta_3 + 0.40 \beta_4 - 0.22 \beta_{12} + 0.19 \beta_{13} + 0.077 \beta_{14} + 0.069\beta_{23} + 0.21\beta_{24} + 0.021 \beta_{34} - 1.74 \beta_1^2 - 0.38 \beta_2^2 - 2.90 \beta_3^2 - 0.30 \beta_4^2$ **(5)**

$SG = 2.72 + 0.45 \beta_1 + 0.32 \beta_2 + 0.75 \beta_3 + 0.26 \beta_4 - 4.866E-003 \beta_{12} - 0.19\beta_{13} + 6.598E-003 \beta_{14} + 0.025 \beta_{23} + 0.026 \beta_{24} + 0.077 \beta_{34} + 0.042 \beta_1^2 + 0.12 \beta_2^2 - 0.39 \beta_3^2 + 0.017 \beta_4^2$ **(6)**

$WR = 41.06 + 1.59 \beta_1 + 0.21 \beta_2 + 4.49 \beta_3 + 0.14 \beta_4 - 0.22 \beta_{12} + 0.38 \beta_{13} + 0.070 \beta_{14} + 0.043 \beta_{23} + 0.18\beta_{24} - 0.056 \beta_{34} - 1.88 \beta_1^2 - 0.59 \beta_2^2 - 2.61 \beta_3^2 - 0.42 \beta_4^2$ **(7)**

Where, WL, SG, WR are water loss, solute gain and weight reduction respectively, and β_1, β_2, β_3 and β_4 are the coded values of the test variables, immersion time, salt-sugar concentration, solution temperature and solution to fruit ratio respectively, as mentioned earlier.

The presence of positive interaction terms between β_1, β_2, β_3 and β_4 indicated that increase in their levels increased WL, SG and WR. The negative values of quadratic terms of process variables of osmosis indicated that higher values of these variables further reduced WL, SG and WR. The analysis of variance of quadratic regression model demonstrated that equation 5, 6 and 7 were highly significant models, as were

evident from F-test with very low probability value (p model = < 0.0001, < 0.0001 and 0.0002 for WL, SG and WR respectively. This indicates that the linear terms of β_1, β_2, β_3 and β_4 of osmosis were highly significant at 5 percent level.

Response surface and contour plots: Response surface plots as a function of two factors at a time, maintaining all other factors at fixed levels are more helpful in understanding both the main and the interactive effects of these two factors. The response surface curves were plotted to understand the interaction of the variables and to determine the optimum level of each variable for maximum response. The 3D surface and contour plots for WL, SG and WR along with overlay plots are shown in figs. 1-4 respectively. Figures show the effects of process variables such as β_1, β_2, β_3 and β_4 on WL, SG and WR during the osmotic dehydration of Oyster mushrooms. The higher processing temperature and immersion time promote rapid water loss and solute uptake along with increased salt-sugar concentration and STFR. Temperature has an effect on the cell membrane permeability that could allow solute to enter by losing its selectivity. Decrease of solution viscosity at higher temperature may influence salt gain due to fact that lower viscosity decreases the resistance to diffusion of solutes into the sample tissue. Increased

Table 4. Range of process parameters and their importance for optimization of osmotic dehydration and solution generated through the RSM Technique in salt-sugar solution.

Process parameters	Goal	Experimental range	Importance	Optimum values	Desirability
Time (min)	is in range	30 - 90	3	44.21	
Salt (%) : Sugar (°B)	is in range	15:45 - 65	3	15 : 52.57	
Temp (°C)	target	36	3	42.30	
STFR	is in range	4:1 - 8:1	3	4.99 : 1	
Responses				**Predicted values**	0.660
WL (g/100g of initial mass)	maximize	32.16 - 46.64	3	41	
SG (g/100g of initial mass)	minimize	0.984 - 3.74	3	2.14823	
WR (g/100g of initial mass)	maximize	31.18 - 44.21	3	38.599	

concentration of the salt solution also led to increase in salt gain. This is probably due to an increase of osmotic pressure gradient and consequent loss of functionality of cell plasmatic membrane that allows solute to enter.

Rapid loss of water and uptake of solute near the surface in the beginning may result in structural changes leading to crust formation/compaction of surface layers and which results in increased mass transfer resistance for water and solutes (Alam *et al.*, 2010). During osmotic dehydration, water removal from the product is always accompanied by the simultaneous counter diffusion of solutes from the osmotic solution into the tissue. In most common operating conditions, mass transfer mainly occurs during the first 2 h for water loss and first 50 min for solute gains (Rault *et al.*, 1989). Further, Rezagah *et al.* (2010) confessed that moisture loss occurs in the first hour of the osmotic process. The mass transfer rates thus become progressively lower with time and water loss stops, whereas solute gain goes on increasing regularly (Ertekin and Çakaloz, 1995). Rapid removal of water in the early stages of osmotic dehydration has been reported by several authors (Lazarides *et al.*, 1995; Ertekin and Çakaloz, 1996; Shi and Le Maguer, 2002). Moreover, mixture of sugar and salt solutions in osmotic dehydration process proved the best choice based on effectiveness, convenience and flavour (Dehkordi, 2010; Manafi *et al.*, 2010).

Optimization of osmotic dehydration of mushroom: Design-Expert trail version 8.0.7.1 (Statease Inc., Minneapolis, USA) was used for getting optimal values for multiple responses, as discussed earlier. Graphical multi-response optimization technique was adopted to determine the workable optimum conditions for the osmotic dehydration of Oyster mushrooms. The contour plots for all the responses were superimposed and regions that best satisfy all the constraints were selected as optimum conditions. The main criteria for constraints optimization were maximum possible water loss, weight reduction and minimum solute gain.

These constraints resulted in feasible zone (yellow coloured area in the superimposed contour plots) of the optimum conditions. Superimposed contour plots having common superimposed area of all the responses for osmotic dehydration in salt-sugar solution are presented in figs. 1-4. These results clearly indicated the suitability of the developed models.

The optimum range of process parameters obtained for osmotic dehydration of Oyster mushrooms were: 30-90 min immersion time; 15 %:45-65° B salt: sugar concentration; 36° C and 4:1-8:1 solution to fruit ratio. Numerical multi response technique was carried out for optimization of process. Equal importance of '3' was given to all the four parameters. The constraints were set such that the selected variables would be minimum from economical point of view for the most important product attribute. Goal of the present study was to maximize the water loss and weight reduction values as high as possible and to minimize solute as low as possible. The optimum conditions were found to be β_1=44.21min, β_2=15 %: 52.57° B, β_3=42.30° C and β_4=4.99:1. At these optimum conditions, WL, SG and WR were found to be 41, 2.15 and 38.6 (g/100 g of initial mass) with overall desirability value of 0.660. Table 4 shows the software generated optimum conditions i.e. range of process parameters and their importance for optimization of osmotic dehydration and solution generated through the RSM Technique in salt-sugar solution.

Conclusion

Mass exchange evaluation during optimization of osmotic dehydration for Oyster mushrooms in salt-sugar solution was carried out to increase process efficiency of osmotic dehydration process, so that this technique could be beneficially practiced in larger food industries. Analysis of variance showed that the effects of all the process variables including solution temperature, immersion time, salt concentrations and STFR were statistically significant. Second order polynomial models were obtained for predicting water loss, solute gain and weight reduction. The optimal conditions for maximum water loss and weight reduction and minimum solute gain corresponded to immersion time 44.21 min, sucrose concentration of 52.57 %, solution temperature 42.3° C and STFR 4.99:1 was 41 (g/100 g of initial mass), weight reduction of 38.6 (g/100 g of initial mass) and solute

gain 2.15 (g/100 g of initial mass) respectively. However, quality characteristics such as colour, taste, texture, shrinkage and rehydration effects should also be investigated to achieve the desired final product specifications for commercial processing.

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