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Optimization of Process Parameters on Osmotic Dehydration of Radish Slices

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Abstract— Response surface methodology was used to determine for optimum processing condition that yield maximum water loss and weight reduction and minimum solid gain during osmotic dehydration of radish in salt solution. The experiments were conducted according to Box-Behnken Design. The independent process variables for osmotic dehydration were processing time (30-120min), temperature (40-60°C) and salt concentration (6-10%w/w). The osmotic dehydration process was optimized for water loss, solid gain, and weight reduction. The optimum conditions were found to be; temperature = 44.575°C, immersion time =30min, salt concentration =6%. At this optimum point, water loss, solid gain and weight reduction were found to be (27.87g/100g initial sample), (1.05g/100g initial sample) and (26.83 g/100g initial sample), respectively.

Keywords— Response surface methodology, Box-Behnken Design, Optimization, Raddish

1. Introduction

An edible root vegetable of the Brassicaceae family (Raphanus sativus) is raddish. Radishes are cultivated and used throughout the world. Raddishs are varying in size, color and duration of required cultivation time and have numerous varieties. Some radishes that are grown for their seeds; oilseed radishes are grown, for oil production [1]. Radishes are a good source of vitamin B6, riboflavin, magnesium, copper and calcium and rich in ascorbic acid, folic acid and potassium. Approximately, one cup of sliced radish bulbs supports 20 calories or less, coming largely from carbohydrates, making radishes, relative to their size, a very filling food for their caloric value [2]. Osmotic dehydration (OD) and drying processes are promising food preservative techniques that may lead products to low MC and a_w [3]. Osmotic dehydration is a widely used technique that removes water from fruits and vegetables by immersion in aqueous solution of sugar and /or salts at high concentration. During osmotic dehydration, two major simultaneous counter-current flows occurs, water flows out of the food into the solution and transfer of solute from the solution into the food [4]. There are numerous studies on osmotic dehydration of vegetables [5] and some work has been carried out on optimization of vegetables by RSM method [6], [7]. Osmotic dehydration (OD) is a food preservation technique that relies on the reduction of water activity and humidity of the product, which has advantages over other dehydration techniques because it preserves the sensory and nutritional characteristics of foods [8], [9]. Mass transfer during osmotic dehydration are influenced by several factors including temperature, concentration of the osmotic medium, size of the sample, sample to solution ratio [10]. Besides reducing the drying time osmotic dehydration is used to treat fresh produce before further processing to improve sensory, functional and nutritional properties. It has been proven to improve the textural characteristics of thawed fruits and vegetables [11], [12]. The incomplete removal of water from a food product by means of an osmotic agent (sugar or salt solution) is called osmotic dehydration and major advantage of this process is its influence on the principal drying method, shortening of the drying process, resulting in lower energy requirements [13]. The response surface methodologies (RSM) are very useful techniques for optimization and applied in different food processes among that is osmotic dehydration [14]- [15]. Osmotic dehydration reduce the number of experiments needed to obtain statistically valid results that is the major advantage and is faster and more informative than traditional assessments which evaluate one variable at a time [16]. The objective of this work was to study the osmotic dehydration of raddish slices as a function of immersion time, temperature and salt concentration through Response surface methodology (RSM) in order to identify process conditions for a high water loss at maximum solid uptakes and to optimize the osmotic dehydration as a pretreatment.

2. Materials and Methods

2.1 Sample Preparation and Experimental Method

Fresh radish was purchased from the organic farm market in Insein Township, Yangon Region. They were washed, peeled with a sterile knife and cut in to uniform slices (5mm thickness). Osmotic dehydration was done in salt solution with different concentrations such as 6, 8 and 10 percent. The sample to solution ratio was constant 1:5 (w/w). The radish slices were weighed and submerged in salt solution at 40, 50 and 60°C. The temperature was maintained constant using a hot water bath. The samples were removed from the solution at different time intervals of 30, 75 and 120 min. In each of the experiments, fresh osmotic solutions were used. After removing from the salt solution, the samples were drained and the excess solution at the surface was removed with filter paper for subsequent weight measurement. After dehydration the samples were dried in hot air oven at 60°C until equilibrium moisture content is obtained. All experiments were done triplicates and the average value was taken for calculation.

2.2 Water Loss, Solid gain and Weight Reduction

Water Loss (WL), Solid Gain (SG) and Weight Reduction (WR) were calculated and given in Eq (1-3) [17].

$$\text{Water Loss} = \text{Solid Gain} + \text{Weight Reduction} \qquad \text{---------}(1)$$

$$\text{Solid Gain} = \frac{(m - m_o)}{M_o} \times 100 \qquad \text{---------}(2)$$

$$\text{Weight Reduction} = \frac{(M_o - M)}{M_o} \qquad \text{---------}(3)$$

Where, M_o- Initial mass of the samples (g)
M-Mass of sample after dehydration (g)
m_o- Initial mass of the solids in sample(g)
m- Mass of the solids in the sample after dehydration (g)

2.3 Design of Experiment

The Response Surface Methodology was applied to the experimental data. RSM is a statistical modeling technique employed for multiple regression analysis using quantitative data obtained from properly designed experiments. The Box-Behnken Design (BBD) of three variables and seventeen trials were used for designing the experiments of osmotic dehydration [18].

Table 1. Codes and Actual Levels of the Independent Variables for the Design of Experiment

Independent Variables	Notations	Coded Levels		
		-1	0	+1
Duration of osmosis (min)	A	30	75	120
Temperature of solution	B	40	50	60

(ºC)				
Salt Concentration (ºBrix)	C	6	8	10

The response surface methodology assumes that there is a polynomial function that relates the responses to the independent variables namely Duration of osmosis (A), Temperature of the solution (B) and Salt concentration (C) in the process. Therefore, the experimental data obtained from the design (Table. 1) were fitted to a polynomial of the form found in equation 4 (Montgomery, 1991).

Response (Y) = $a_0 + a_1A + a_2B + a_3C + a_{11}A^2 + a_{22}B^2 + a_{33}C^2 + a_{12}AB + a_{13}AC + a_{23}BC$…… (4)

where the response (Y) is (WL, SG and WR %), the b_{an} are constants and A, B, C are independent variables.

2.4 Optimization

Optimization was carried by attempting to combine various factors that simultaneously satisfy the requirements placed on each of the response and factors. There are several response variables describing the quality characteristics and performance measurements of the system, are to be maximized while some are to be minimized. RSM was applied to determine the optimum conditions for producing a model for osmotic dehydration of raddish slices with maximum water loss, weight reduction and minimum solid gain.

3. Results and Discussion

3.1 Effect of Variables on Water Loss, Solid Gain and Weight Reduction

The effects of variation in water loss, solid gain and weight reduction were studied by changing the osmotic solution temperature, osmotic solution concentration and duration and a second order polynomial equation was fitted with the experimental data.

3.2 Statistical Analysis on Model Fitting

The experimental responses as a function of process variables such as Time (A), Temperature (B) and Sugar Concentration (C) during osmotic dehydration of raddish slices are shown in Table 1.

Table 1. The Box-Behnken Design for Osmotic Dehydration of Raddish Slices

	Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3
Run	A:time	B:Temp	C:Sugar	WL	SG	WR
1	120	50	10	25.4	4.96	20.42
2	75	50	8	27.9	3.9	24
3	75	60	10	24.24	4.81	19.43
4	30	40	8	24.88	2.25	22.63
5	30	60	8	22.75	3.34	19.41
6	30	50	10	29.88	4.52	25.36
7	75	40	6	22.58	1.14	21.44
8	75	60	6	20.11	2.8	17.31
9	75	40	10	22.79	4.02	18.77
10	75	50	8	27.81	3.78	24.03
11	30	50	6	28.87	1.5	27.37
12	120	60	8	20.31	4.52	15.79
13	75	50	8	27.33	3.62	23.71
14	120	50	6	23.34	2.71	20.63
15	120	40	8	19.71	2.48	17.23

The value of water loss (%), solid gain (%) and weight reduction (%) were within the ranges of 19.71-29.88, 1.14-4.96 and 15.79-27.37 respectively. Regression analysis and ANOVA results are shown in Table 2. The model F values of three responses such as WL, SG and WR were 72.60, 87.67 and 57.15 implying that the model is significant. At the same time WL, SG and WR showed that they possess non -significant lack- of-fit. These values indicated that the models were fitted and reliable. The adequacy of the model is further checked by Coefficient of determination (R^2) was found to be 0.9924, 0.9937 and 0.9904 for WL, SG and

WR respectively. As the calculated R^2 was found to be approximately equal to 1 it was considered to be high enough for predication purposes and the predicted R^2 for WL, SG and WR of 0.8957, 0.9271 and 0.8516 were in reasonable agreement with adjusted R^2 of 0.9787, 0.9824 and 0.9730. The values of R^2 and adjusted R^2 obtained in the study implied that the predicted values are in good agreement with the experimental values. The values of Adeq precision are 26.6337, 30.7877 and 25.3272 for WL, SG and WR respectively. The values of Adeq precision obtained in this study are greater than 4.0 indicating that these responses had better precision and reliability. The values of coefficient of variation (C.V %) were 1.95,4.66 and 2.56 for WL, SG and WR respectively which showed that the deviations between experimental and predicted values are low.

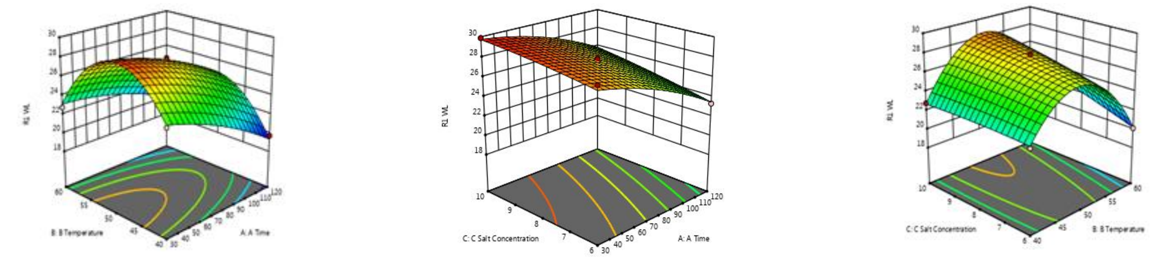
Table 2. Regression Coefficients for Osmotic Dehydration of Raddish Slices

Variables/ Factor	DF	Water Loss (%)		Solid Gain (%)		Weight Reduction (%)	
		Sum of Squares	F-value	Sum of Squares	F-value	Sum of Squares	F-value
Model	9	149.23	72.60	19.33	87.67	151.48	57.15
A-time	1	38.81	169.92	1.17	47.77	53.56	181.87
B-Temp	1	0.8128	3.56	3.89	158.84	8.26	28.05
C-Sugar	1	6.86	30.05	12.90	526.59	0.9591	3.26
AB	1	1.86	8.16	0.2256	9.21	0.7921	2.69
AC	1	0.2756	1.21	0.1482	6.05	0.8100	2.75
BC	1	3.84	16.82	0.1892	7.72	5.74	19.48
A^2	1	1.62	7.10	0.1398	5.71	0.8171	2.77
B^2	1	96.23	421.33	0.6656	27.16	80.80	274.35
C^2	1	0.0776	0.3399	0.0826	3.37	0.0000	0.0001
Lack of Fit		0.9541		0.0830		1.41	
R^2		0.9924		0.9937		0.9904	
Adjusted R^2		0.9787		0.9824		0.9730	
Predicted R^2		0.8957		0.9271		0.8516	
Adeq Precision		26.6337		30.7877		25.3272	
Std. Dev.		0.4779		0.1565		0.5427	
Mean		24.53		3.36		21.17	
C.V. %		1.95		4.66		2.56	

3.3 Effect of Process Variables on Water Loss

During the early stages of osmotic dehydration of raddish slices, the increase in osmotic solution concentration from 6 to 10%w/w enhanced the mass transfer properties (WR, SG and WL) (Fig.1). Because of the fact that smaller molecular weights of the solute (salt) strongly infiltrate into the plant tissue and increases the outflow of water from the inner tissue fastly to the osmotic solution and enhanced the WR and WL [19]. Water loss is an important parameter in osmotic dehydration and which indicates the amount of moisture diffused from the sample to solution. The regression model of water loss as a function of process parameters is given in equation (5) .The presence of negative interaction term between A, B indicated that increase in their level decreased water loss. The positive values of quadratic terms of process variables of osmosis indicated that higher values of these variables increased water loss.

$$\text{Water loss} = +27.68 - 2.2*A - 0.3188*B + 0.9262*C - 0.6625*A^2 - 5.1*B^2 - 0.145*C^2 + 0.6825*A*B + 0.2625*A*C + 0.98*B*C \quad \text{-----(5)}$$



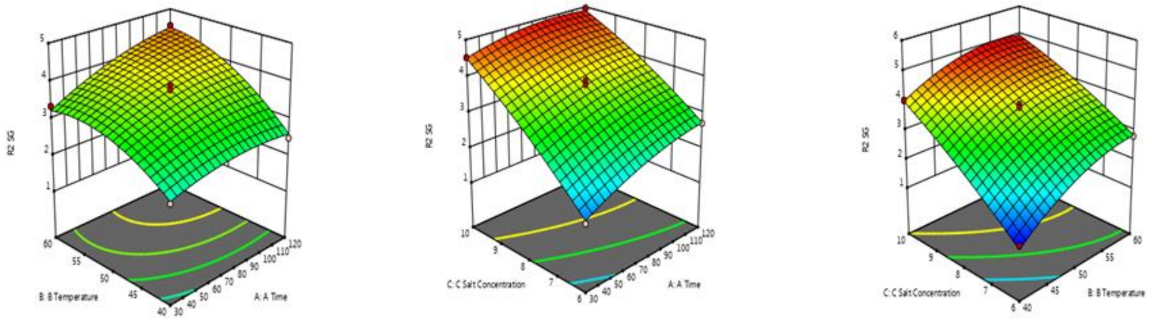
(a) immersion time and temperature (b) salt concentration and time (c) salt concentration and temperature

Figure (1) Effect of Process Variables on Water loss

3.4 Effect of Process Variables on Solid Gain

The effect of osmotic solution temperature on the mass transfer properties of the raddish slices and the consequences were depicted in Fig.2. The present results are also in agreement with findings of [20] obtained during the optimization of the osmotic dehydration of peach slices. This positive interaction between process time and osmotic agent concentration was also reported by [21] during the osmotic dehydration studies on beetroot in salt solution. The regression model of solid gain as a function of process parameters for osmotic dehydration of raddish slices are given in equation (6). The positive values of interaction term between A, B and C indicated that increase in their level increased solid gain. The negative values of quadratic terms of process variables for osmotic dehydration of raddish slices indicated that higher values of these variables affected solid gain.

$$\text{Solid Gain} = +3.77+0.3825*A + 0.6975*B+ 1.27*C - 0.1946*A^{2} - 0.4247*B^{2} -0.1496* C^{2} +0.2375*A*B-0.1925*A*C+0.2175*B*C \text{---(6)}$$



(a) immersion time and temperature (b) sugar concentration and time (c) sugar concentration and temperature

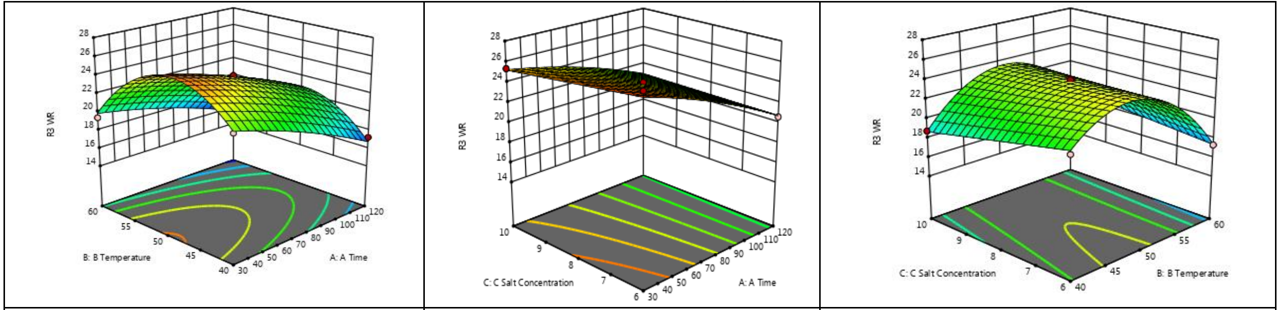
Figure (2) Effect of Process Variables on Solid Gain

3.5 Effect of Process Variables on Weight Reduction

Weight reduction indicates the amount of water lost by the sample during the osmotic dehydration process. The regression model of weight reduction as a function of process parameters are given in equation (7). The presence of negative values of interaction term between A, B and C indicated that increase in their level decreased weight reduction. The positive values of quadratic terms of process variables of osmotic dehydration of toddy tubes indicated that higher values of these variables reduced weight reduction. The response surface plot for osmotic dehydration of toddy tubes indicated in Figure 3 represents weight reduction as a function of time, temperature and concentration of the osmotic solution. Weight reduction increases with increase in sugar concentration and time as shown in Figure 3. The reason was that the viscosity of osmotic solution was lowered and the diffusion coefficient of water increases at high temperature.

$$\text{Weight reduction} = +23.91- 2.59*A-1.02*B-0.3463*C -0.4704*A^{2}-4.68*B^{2}+0.0021C^{2} + 0.445*A*B$$

$$+0.45*A*C +1.2*B*C \qquad \text{---------(7)}$$



(a) immersion time and temperature

(b) sugar concentration and time

(c) sugar concentration and temperature

Figure (3) Effect of Process Variables on Weight Gain

3.6 Numerical Optimization of Process Parameters

The criteria variables were set such that the independent variables (Time, Temperature and Concentration) would be minimum from an economical point of view [22]. The main criteria for constraints optimization for osmotic dehydration of raddish slices were maximum possible water loss and weight reduction. The desired goals for each variables and responses are shown in Table 4. In order to optimize the process parameters for osmotic dehydration of raddish slices by numerical optimization which finds a point that maximize the desirability function; equal importance of `3' was given to all three process variables and three responses.

Table 4. Criteria and Output for Numerical Optimization of Process Parameters

Criteria	Goal	Lower limit	Upper limit	Importance	Output
A:Time	minimize	30	120	3	30
B:Temp	minimize	40	60	3	44.575
C:Salt	minimize	6	10	3	6
Water loss (%)	maximize	19.71	29.88	3	27.984
Solid Gain (%)	minimize	1.14	4.96	3	1.085
Weight reduction (%)	maximize	15.79	27.37	3	26.894
Desirability					0.919

3.7 Verification of the Model for Osmotic Dehydration of Raddish Slices

Osmotic dehydration experiments were conducted at the optimum process condition (A= 30 min, B=44.575°C and C=6%w/w) for testing the adequacy of the model equations for predicting the response values. The experimental values (mean of three experiments) and predicted values by the equations of the model are displayed in Table 5. The observed experimental values were seen to be very close to the predicted values of responses such as water loss, solid gain and weight reduction. Therefore, it could be concluded from above discussion that model are quite adequate to assess the behavior of the osmotic dehydration of raddish slices.

Table 5. Predicted and Experimental Values of Response at Optimum Process Conditions for Osmotic Dehydration of Raddish Slices

Response	Predicted Value	Observed Value
Water loss (%)	27.984	27.87
Solid Gain (%)	1.085	1.05
Weight reduction (%)	26.894	26.83

4. CONCLUSION

Response surface methodology was effective in optimizing process parameters for the osmotic dehydration of raddish slices in osmotic aqueous solution of salt having concentration in the range of 6-10, temperature

40-60°C and process duration 30-120min. The results showed that, all the independent variables have considerable influence on the osmotic dehydration process of raddish slices. There were three second order polynomial models and these were framed for three responses (WR, SG and WL) from the observed data. In this study, the obtained regression equations can be used for optimum conditions of desired responses within the range of conditions.

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