Optimization of Process Parameters on Osmotic Dehydration of Radish Slices using Response Surface Methodology (RSM)

K.Deepika[1], V.Gayathri[2]

[1] *Tamil Nadu Agricultural University,ddeepikak48@gmail.com*
[2] *Tamil Nadu Agricultural University, gaya3fp@gmail.com*

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 temperature (40-60°C), processing time (30-150min) and salt concentration (5-10%w/w). The osmotic dehydration process was optimized for water loss, solid gain, and weight reduction. The optimum conditions were found to be; temperature = 44.61°C, immersion time =30min, salt concentration =5%. At this optimum point, water loss, solid gain and weight reduction were found to be (27.99g/100g initial sample), (1.08 g/100g initial sample) and 26.45 g/100g initial sample, respectively.

Key words: Optimization, osmotic dehydration, radish, response surface methodology

1. Introduction

White radish (Raphanus *sativus*) is a popular edible root vegetable which is grown and consumed through out Asia. It belongs to the Brassicaceae family. Radishes have numerous varieties, varying in size, color and duration of required cultivation time. Radishes are rich in ascorbic acid, folic acid and potassium (USDA).

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. Two major simultaneous counter-current flows occurs during osmotic dehydration water flows out of the food into the solution and transfer of solute from the solution into the food (Madamba, 2003;Sereno *et al*.,2001).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(Raoult- Wack,1994;Rastogi and Raghavarao,1994). 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 (Chiralt *et al*.,2001; Talens *et al*.,2002).There are numerous studies on osmotic dehydration of vegetables (Mudahar *et al.*,1989;Kar and Gupta,2001;Sutar and Gupta,2007) and some work has been carried out on optimization of vegetables by RSM method (Uddin,2004;Corzo and Gomez,2004;Singh *et al*.,2008) .

The objective of this work was to study the osmotic dehydration of radish slices as a function of salt concentration, temperature and immersion time through Response surface methodology (RSM) in order to indentify process conditions for a high water loss at minimal solid uptakes and to optimize the osmotic dehydration as a pretreatment

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to further processing.RSM has been used by several investigators for optimizing food process operation (Ravinderan and Chattopadhyay, 2000)

2. Materials and Methods

The methodology involved osmotic dehydration with different salt concentration, determination of water loss, solid gain, weight reduction and optimization of response parameters with RSM.

2.1 *Sample preparation and Experimental method*

Fresh radish was procured from the local markets of Coimbatore. They were washed, peeled with a sterile knife and cut in to uniform slices (5mm thickness). The initial moisture content was determined by using oven method at 70°C for 18h (AOAC,1990)

Osmotic dehydration was done in salt solution with different concentrations such as 5, 7.5 and 10 percent. The sample to solution ratio was constant 1:5 (w/w). The radish slices was 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, 90 and 150 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 tray drier at 50°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) (Ozen *et al*.,2002 and Singh *et al*., 2007)

$$\text{Water Loss}(\%) = \text{WR} + \text{SG} \qquad \text{---------(1)}$$

$$\text{Solid Gain}(\%) = \frac{(\text{m}-\text{m}_\text{O})}{\text{M}_\text{O}} \times 100 \qquad \text{-------(2)}$$

$$\text{Weight Reduction }(\%) = \frac{\text{M}_0-\text{M}}{\text{M}_0} \qquad \text{---------(3)}$$

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 (Box-Behnken,1960).

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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	90	150
Temperature of solution(°C)	B	40	50	60
Salt concentration (%)	C	5	7.5	10

The osmotic dehydration was assumed to be affected by three independent variables namely Duration of osmosis (A), Temperature of the solution (B) and Salt concentration (C). The dependent variables referred as responses Y.

$$Y = a_0 + a_1 A + a_2 B + a_3 C + a_{11}A^2 + a_{22}B^2 + a_{33}C^2 + a_{12}AB + a_{13}AC + a_{23}BC \text{----(4)}$$

Where ,

Y is the response (WL, SG and WR%); a_n are the constant regression coefficients; and A,B,C are independent variables

2.4 *Optimization*

Optimization was performed by attempting to combine various factors that simultaneously satisfy the requirements placed on each of the response and factors. Usually 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 used to determine the optimum conditions for producing a model for osmotic dehydration of radish 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 variable like Time (A), Temperature (B) and Salt concentration(C) during osmotic dehydration of radish slices are summarized in Table 1.

Table 1. The Box-Behnken design for osmotic dehydration of Radish slices

S.No	Time(min)	Temp(°C)	Conc(%)	WL(%)	SG(%)	WR%)
1	90	40	5.00	22.59	1.14	21.45
2	90	60	10.0	24.25	4.81	19.44
3	30	50	5.00	28.88	1.50	27.38
4	90	50	7.50	27.73	3.86	23.87
5	150	50	5.00	23.53	2.73	20.80
6	30	50	10.0	29.89	4.53	25.36

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7	150	60	7.50	20.32	4.53	15.79
8	150	40	7.50	19.72	2.49	17.23
9	150	50	10.0	25.40	4.97	20.43
10	90	50	7.50	27.95	3.92	24.03
11	30	40	7.50	24.89	2.25	22.64
12	90	50	7.50	27.35	3.63	23.72
13	90	40	10.0	22.80	4.02	18.78
14	90	50	7.50	27.82	3.79	24.03
15	30	60	7.50	22.78	3.34	19.44
16	90	60	5.00	20.12	2.70	17.42
17	90	50	7.50	27.74	3.80	23.94

The value of water loss (%), solid gain (%) and weight reduction (%) were within the ranges of 19.72-29.89,1.14-4.97 and 15.79-27.38 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 117.29, 110.55 and 91.10 implying that the model is significant. At the same time WL and SG showed that they posses 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 0.9934 , 0.9930 and 0.9915 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. The predicted R^2 for WL,SG and WR of 0.9118,0.9221 and 0.8704 were in reasonable agreement with adjusted R^2 of 0.9849, 0.9840 and 0.9807.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 34.139,36.272 and 32.723 for WL,SG and WR respectively, Adeq precision obtained in this study is greater than 4.0 indicating that this response had better precision and reliability. The values of coefficient of variation (C.V %) were 1.60, 4.15 and 2.08 for WL,SG and WR respectively which indicated that the deviations between experimental and predicted values are low.

Table 2: Regression coefficients for osmotic dehydration of radish 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	166.97	111.29	19.91	110.55	163.68	91.10
A	1	38.15	241.18	1.20	60.04	52.89	264.93
B	1	0.9	5.06	3.75	187.62	85.02	40.17
C	1	6.52	41.19	13.16	657.69	1.16	5.79
A^2	1	1.79	11.34	0.15	7.70	0.90	4.49
B^2	1	111.14	702.64	0.88	43.81	92.28	462.24
C^2	1	0.083	0.52	0.13	6.54	5.457	0.027
AB	1	1.84	11.61	0.23	11.28	0.77	3.88
AC	1	0.18	1.17	0.16	7.80	0.68	3.14
BC	1	3.84	24.29	0.15	7.41	5.550	27.55
Lack of fit		6.04		2.64		26.44	
R^2		0.9934		0.9930		0.9915	
Adj.R^2		0.9849		0.9840		0.9807	
Pred. R^2		0.9118		0.9221		0.8704	
CV(%)		1.60		4.15		2.08	
Std. Dev		0.40		0.14		0.45	
Adeq precision		34.139		36.272		32.723	

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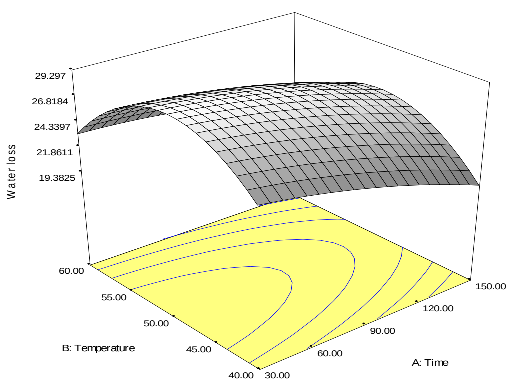
3.3 *Effect of process variables on water loss*

Water loss is an important parameter in osmotic dehydration. Water loss 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.

Water loss=+27.72-2.18*A-0.32*B+0.90*C-0.65*A^2-5.14 B^2-0.14 C^2+0.68*A*B+0.21*A*C+0.98*B*C-----(5)



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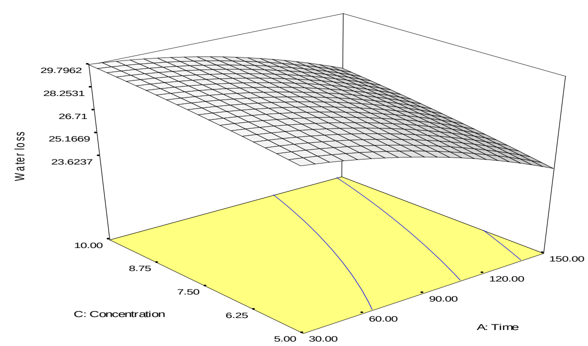

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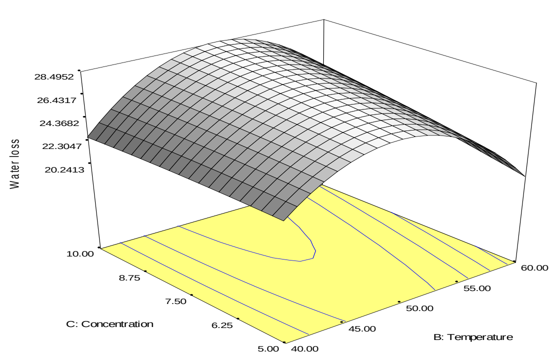

(c)

Fig 1. Water loss during osmotic dehydration of radish as a function of : (a)immersion time and temperature (b) concentration and time (c) Concentration and temperature

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The response surface plot indicated in Figure 1 represents water loss as a function of time, temperature and concentration of the osmotic solution .From Figure 1 it was observed that water loss increases gradually with increase in salt concentration and temperature. This might be due increase in temperature decreases the concentration of the solution and thus reduces the external resistance to mass transfer at product surface. (Panades *et al*.,2008). The increase in water loss with increase in immersion time was observed.

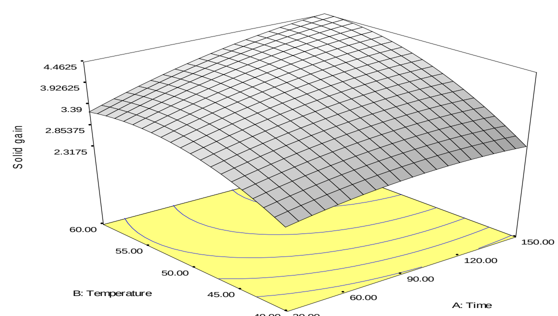
3.4 *Effect of process variables on Solid Gain*

The response surface plot indicated in Figure 2 represents solid gain as a function of time, temperature and concentration of the osmotic solution. As shown in Figure 2b the solid gain increases with osmotic solution concentration this is mainly because of the high concentration difference between the radish slices and osmotic solution .Figure 2c revealed that solid gain increased with increase in osmotic solution temperature. This might be due to decrease in viscosity of the osmotic solution resulting in high diffusion rate of solute (Singh *et al.*,2007)

The regression model of solid gain as a function of process parameters are given in equation (6)

$$\text{Solid Gain}=+3.80+0.39*A+0.69*B+1.28*C-0.19*A^2-0.46*B^2-0.18*C^2+0.24*A*B-0.20*A*C-0.19*B*C \text{---}(6)$$

The presence of positive 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 of osmosis indicated that higher values of these variables affected solid gain.



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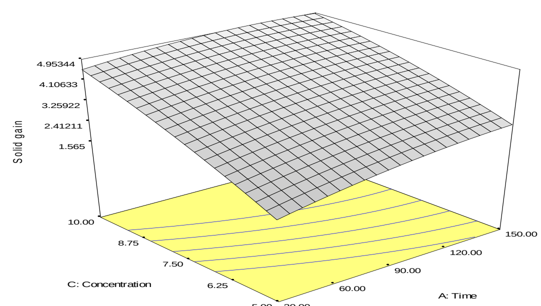

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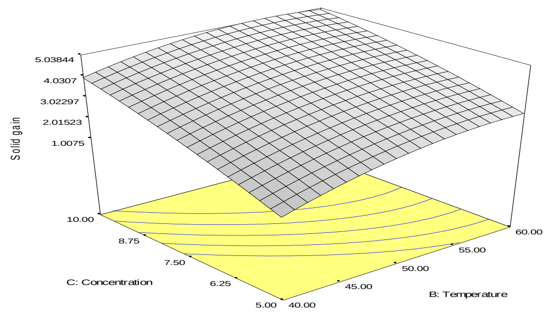


(c)

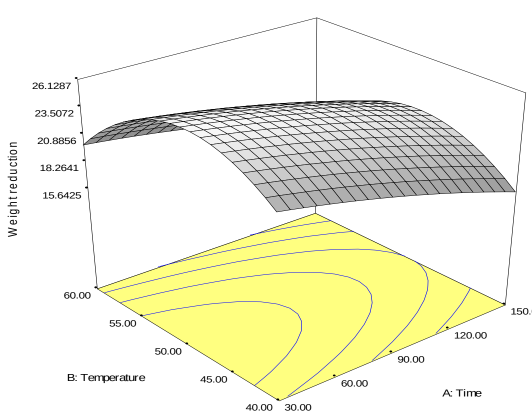
Fig 2. Solid gain during osmotic dehydration of radish as a function of : (a)immersion time and temperature (b) concentration and time (c) Concentration and temperature

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 (6)

Weight reduction $=+23.92-2.57*A-1.0*B-0.38*C-0.46*A^2-4.68*B^2+0.36C^2+0.44*A*B+0.41*A*C+1.17*B*C$-(7)

The presence of negative 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 osmosis indicated that higher values of these variables reduced weight reduction. The response surface plot 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 concentration as shown in Figure 3b. The reason was that the viscosity of osmotic solution was lowered and the diffusion coefficient of water increases at high temperature.



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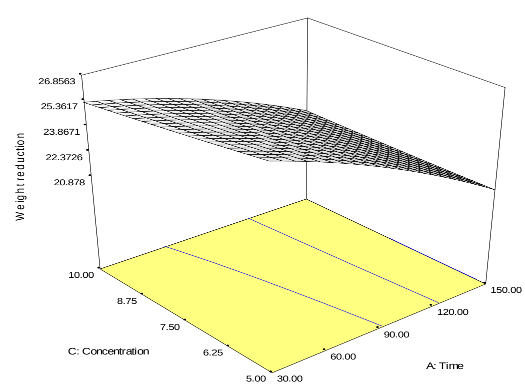

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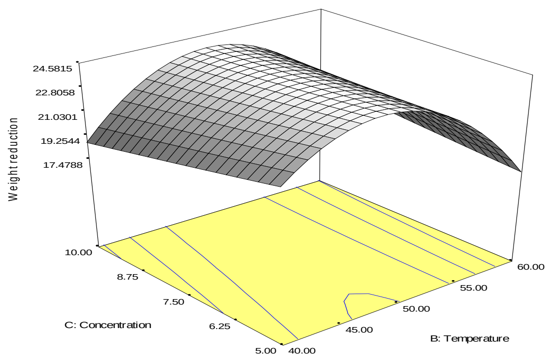

(c)

Fig 3. Weight reduction during osmotic dehydration of radish as a function of : (a)immersion time and temperature (b) concentration and time (c) Concentration and temperature

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 (Jain *et al.*,2011). The main criteria for constraints optimization were maximum possible water loss and weight reduction. The desired goals for each factor and response are shown in Table 3. In order to optimize the process parameters for osmotic dehydration process by numerical optimization which finds a point that maximize the desirability function; equal importance of `3' was given to all the three process parameters and three responses.

Table 3: Criteria and output for numerical optimization of process parameters.

Criteria	Goal	Limit	Importance	Output
Time (min)	minimize	30-150	3	30
Temperature(°C)	minimize	40-60	3	44.61
Concentration (%)	minimize	5-10	3	5
Water loss(%)	maximize	19.72-29.89	3	27.99
Solid gain(%)	minimize	1.14-4.97	3	1.08
Weight reduction (%)	maximize	15.79-27.38	3	26.9
Desirability				0.918

3.7 Verification of the model for osmotic dehydration of radish slices

Osmotic dehydration experiments were conducted at the optimum process condition (A= 30min, B=44.61°C and C=5%) for testing the adequacy of the model equations for predicting the response values. The observed experimental values (mean of three experiments) and values predicted by the equations of the model are presented in Table 4 .The experimental values were found to be very close to the predicted values for 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 radish slices.

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Table 4: Predicted and experimental values of response at optimum process conditions for osmotic dehydration of radish

Response	Predicted Value	Experimental Value
Water loss(%)	27.99	28.25
Solid gain(%)	1.08	1.26
Weight reduction (%)	26.9	26.45

4. Conclusion

It was concluded from this study that the solution temperature and immersion time were the most pronounced factors affecting solid gain and water loss of radish slices during osmotic dehydration followed by salt concentration. Response surface methodology was effective in optimizing process parameters for the osmotic dehydration of radish slices in osmotic aqueous solution of salt having concentration in the range of 5-10, temperature 40-60°C and process duration 30-150min. The regression equation obtained in this study can be used for optimum conditions for desired responses with in the range of conditions in the study.

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Author Biography

K.Deepika completed her B.Tech in Food Process Engineering from Tamil Nadu Agricultural University. Dairy engineering and food preservation and technology are area of her interest.

V.Gayathri completed her M. Tech in Food Processing and Engineering from Karunya University, Coimbatore. Food packaging and extruded food products are areas of her interest