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RESEARCH PAPER

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Optimization of osmotic dehydration of yellow carrot slices using response surface methodology

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SUMMARY :

Response surface methodology is typically used for mapping a response surface over a particular region of interest, optimizing the response or for selecting operating conditions to achieve target specifications. The present investigation aimed to optimize the time, temperature and sucrose concentration for osmo-dehydration of carrots slices to maximize water loss, solute gain, dehydration efficiency, minimum water activity and texture values. The experimental design was found to be significant in terms of p-values less than 0.0500. Numerical optimization showed that 37.53^{0}C temperature, 6.9 hours time, 61.6 ^{0}B sucrose concentration gives the best responses as 66 per cent water loss, 16.8 per cent solute gain, 3.8 DE, 0.49 aW and 44.40 N texture.

KEY **W**ORDS : RSM, Yellow carrots slices, Water loss, Solute gain, Water activity, Texture

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Carrot (*Daucus carota* L.) is an important root vegetable and is widely grown in different parts of India for major consumption during winter season. Different colored varieties are grown in different parts of the nation for their individual purpose. Red carrots are widely grown in Northern India for preparation of sweet desserts like gajar halwa, gajarella, gajar murabba etc. Yellow and orange carrots are mostly grown in southern India for consumption as salad or vegetable curries (Sharma *et al.*, 2012). Despite of the bulk home consumption during season, major portion of vegetable grown suffers post harvest losses due to less moisture, more fibre or less sweet in taste during its early or late harvesting periods. This can be minimized by processing them using low cost, energy efficient osmotic dehydration. Osmotic dehydration is a process of counter-current transfer of mass, in which the solute flows into the food, while moisture is eluted from the interior of the food to the hypertonic solution (Tortoe, 2010). Different solutes can be used for osmotic dehydration depending upon the nature of product to be made. Sucrose, glucose, honey, sugar alcohols are different solutes usually employed for osmotic dehydration. Response surface methodology response surface methodology (RSM) is an important tool in process optimization and product quality improvement. RSM is a collection of experimental design and optimization techniques that enables the researcher to determine the relationship between the response and the independent variables. RSM is typically used for mapping a response surface over a particular region of interest, optimizing the response or for selecting operating conditions to achieve target specifications (Patil *et al*., 2014). Several scientific studies are being carried out for optimizing concentration, time, temperature, solute concentration for osmotic dehydration of fruits and vegetables using responses like water loss, solute gain etc. Although, no significant contribution have been made till now for optimizing osmotic dehydration conditions for yellow carrots. Therefore, the present study was aimed at optimizing osmo-dehydration conditions (time, temperature and concentration) on the basis of five responses (water loss, solid gain, water activity, dehydration efficiency and texture).

EXPERIMENTAL METHODS

Experimental design :

The response surface methodology software design expert (Statease Inc, Minneapolis, USA, Trial version) version 10.0.3.1 was used for optimization of osmotic dehydration of yellow carrots on the basis of effect of process variables on water loss, solid gain, dehydration efficiency (DE), water activity and texture. Time, temperature and concentration were selected as independent variables. Time (2-9 hours), temperature (19-70^{0}C) and concentration (43-70^{0}B) were chosen on the basis of earlier scientific findings (Nadia *et al*., 2013). The optimization aimed at maximum water loss, solute gain, dehydration efficiency while minimum water activity and texture values. Central composite design was used for designing the experimental data. The coded levels of independent variables are shown in Table A.

Responses were assumed according to second order polynomial equation which was fitted to the experimental data of each dependent variable as given. The model proposed to each response of Y was:

$$Y_0=\beta_0+\sum_{I=1}^{3}\beta iiXi+\sum_{I=1}^{3}\beta iiX^2+\sum_{i<j=1}\beta iiXiXj \qquad .....(1)$$

where, β_0, βi, βij are intercepts, quadratic regression co-efficient terms. Xi, X^2 and Xj are independent variables. The model permitted evaluation of quadratic terms of the independent variables on the dependent variable. The response surface and contour plot were generated for different interactions of any two independent variables, where holding the value of third variables as constant at central level (Sridevi and Genitha, 2012).

Raw material and osmotic dehydration process:

Fresh carrots were procured from experimental farms, Department of vegetable science. Carrots were washed in fresh running water, followed by peeling and cutting into 5-7 mm thick slices with stainless steel knives. Slices were blanched in water at 95^{0}C for 2 minutes followed by pricking with stainless steel knives and dipping in osmotic solutions (sucrose) for sufficient period of time as per experimental design shown in Table B. Dipped slices were kept covered in oven maintained at specific temperature. After sufficient dipping time as per experimental design, slices were dried in tray drier at 65^{0}C for 8 hours. The dried slices were analyzed for water loss, solute gain, dehydration efficiency, water activity (aW) and texture. Water loss and solute gain were calculated using the formula (as given by Ozen *et al*. (2002) and Singh *et al*. (2007):

$$\%\ WL = \text{water loss/100g fresh fruit}$$

$$= (W_o - W_t) + (S_t - S_o) / W_o \times 100 \qquad ....(1)$$

$$\%SG = \text{Solute gain/100g fresh fruit}$$

$$= (S_t - S_o)/W_o \times 100 \qquad ....(2)$$

where, W_0 is the initial weight of fruit (g), W_t is the weight of fruit after osmotic dehydration at time t (g), S_0 is the initial dry matter of fruit (g) and S_t is the dry matter of fruit after osmotic dehydration at time t (g). Dehydration efficiency was calculated by dividing water

Table A: Process variables and their coded levels of experimental design

Factor	Name	Units	Type	Subtype	Coded levels		
					-1	0	1
a	Temperature	^{0}C	Numeric	Continuous	30	45	60
B	Time	hr	Numeric	Continuous	4	86	8
C	Concentration (sucrose)	^{0}B	Numeric	Continuous	50	60	70

Table B : Experimental design and results in terms of responses

	Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3	Response 4	Response 5
Run	A:Temperature	B:Time	C:Concentration	Water loss	Solid gain	DE	aW	Texture
	^{0}C	hour	^{0}B	%	%	-	-	N
1	45	6	60	66.23	16.72	3.96	0.48	44.72
2	45	6	60	66.23	16.72	3.96	0.48	44.72
3	45	6	60	66.23	16.72	3.96	0.48	44.72
4	70	6	60	74.22	12.3	6.03	0.45	48.34
5	70	6	60	74.22	12.3	6.03	0.45	48.34
6	45	6	60	66.23	16.72	3.96	0.48	44.72
7	45	6	60	66.23	16.72	3.96	0.48	44.72
8	45	6	60	66.23	16.72	3.96	0.48	44.72
9	60	4	50	61.88	15.67	3.94	0.58	39.79
10	60	8	70	75.16	12.2	6.16	0.42	49.56
11	60	8	50	66.23	15.09	4.38	0.46	45.29
12	60	4	70	69.84	14.5	4.62	0.46	47.12
13	45	6	60	66.23	16.72	3.96	0.48	44.72
14	45	6	60	66.23	16.72	3.96	0.48	44.72
15	45	6	60	66.23	16.72	3.96	0.48	44.72
16	19	6	60	60.02	17.53	3.42	0.61	38.08
17	19	6	60	60.02	17.53	3.42	0.61	38.08
18	45	9	60	68.43	15.1	4.53	0.47	46.29
19	45	2.5	60	62.83	15.5	4.05	0.57	40.89
20	45	6	60	66.23	16.72	3.96	0.48	44.72
21	45	6	42	56.42	18.02	3.13	0.62	37.47
22	30	8	70	68.68	15.43	4.45	0.49	46.08
23	30	8	50	61.92	15.79	3.92	0.58	40.12
24	30	4	50	58.23	15.1	3.85	0.6	38.2
25	30	4	70	66.12	15.43	4.28	0.56	44.53

loss with solute gain observed (Ramallo and Mascheroni, 2005). Water activity was measured using water activity meter (Labswift a_w, Novasina, Switzerland). Texture was measured with Texture Analyzer Model TMS-Pro from Food Technology Corporation, U.S.A. having a load cell of 250 N. A 4 mm cylindrical probe was used for IMF slices in conjunction with texture analyzer. The hardness of products was noted in Newton (N).

EXPERIMENTAL FINDINGS AND ANALYSIS

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Optimization of osmo-dehydration conditions *i.e.* temperature, time and concentration on the basis of effect on water loss, solute gain, dehydration efficiency, water activity and texture through response surface methodology was predicted on the basis of p-values <0. 0500 indicating significant models. In this case, a, B, C, aB, aC, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. Fit statistics showed mean values 65.86, 15.79, 4.23, 0.50 and 43.82 for water loss, solute gain, dehydration efficiency, water activity, texture and implies goodness of fit. The goodness of fit of model is checked by determination co-efficient (R^2) according to Patil *et al.* (2014). The predicted R^2 of 0.99, 0.99,0.97, 0.96 and 0.99 found to be in agreement with adjusted R^2 0.99, 0.98, 0.95, 0.93, 0.98 for water loss, solute gain, dehydration efficiency, water activity and texture. The model therefore, was found to be significant for this experimental

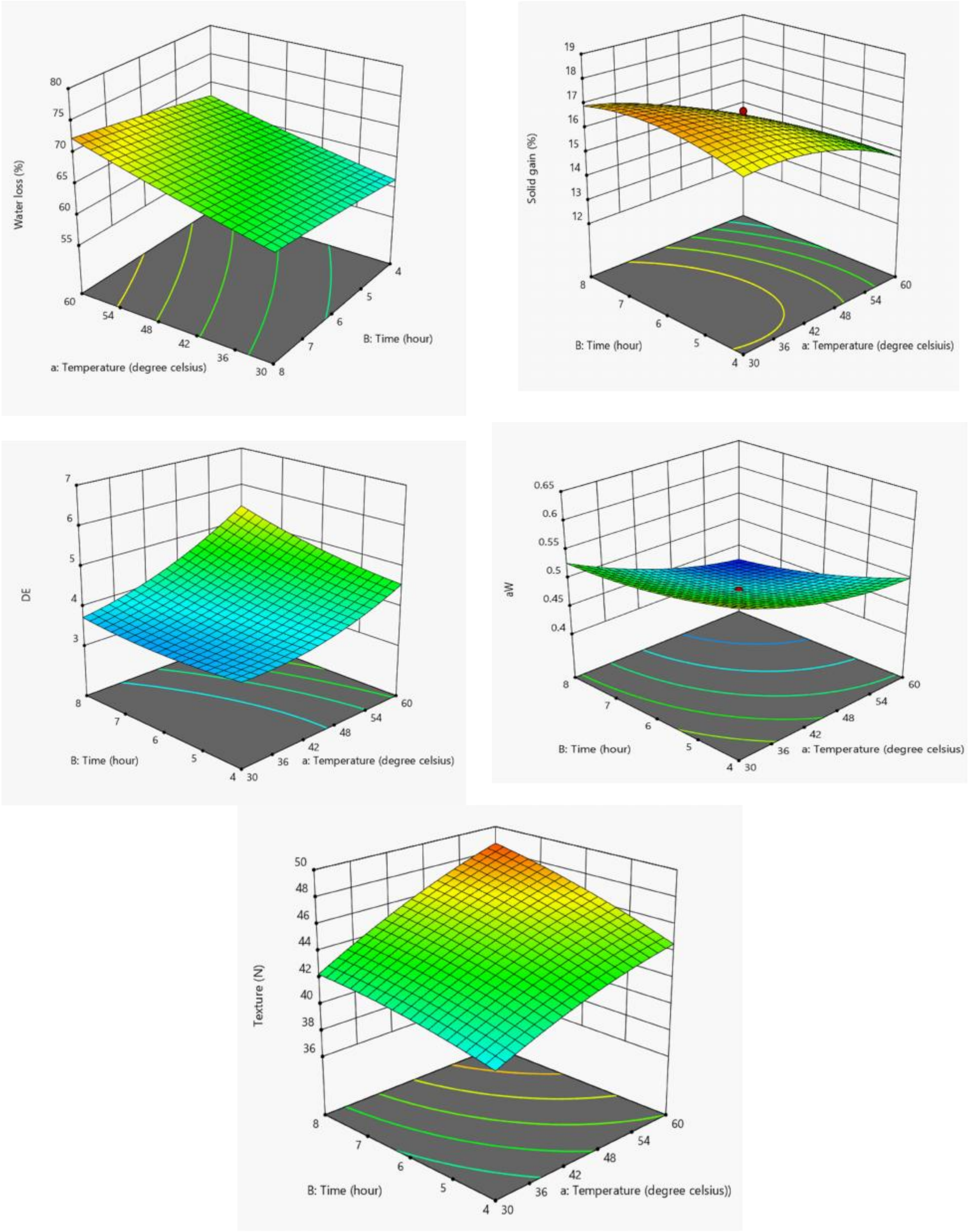

Fig. 1: 3-D surface plots showing effect of time, teperature and concentration on water loss (WL), solute gain (SG), Dehydration efficiency (DE), water activity (aW) and texture of osmo-dried carrots slices

design. The effect of variables on all the responses has been showed in Fig.1.

Influence of process conditions on water loss:

Restricted maximum likelihood analysis indicate that temperature, time and concentration had significant effects on water loss and the quadratic model developed in coded form (at 95% confidence interval) excluding the non-signficant terms is presented as below:

$$\text{Water loss} = +66.38+3.63a+1.83B+3.95C+0.4275aB+0.2800aC-0.0200BC+0.3012a^2-0.1820B^2-0.9675C^2 \quad ....(4)$$

The inceased water loss may be due increase in permeability of cell membrane of vegetables due to higher temperature and more time given for osmosis to result favouring higher mass transfer (Lazarides and Mavroudis, 1995; Uddin *et al*., 2004 and Barat *et al*., 2001). The criteria for optimization was selected on the basis of maximum water loss, maximum solute gain, maximum dehydration effiiciency, minimum water activity and minimum texture values. The p-values less than 0.0500 obtained by analysis indicate that temperature, time, sucrose concentration and interaction of temperature with time and concentration have significant effect on water loss at 95 per cent confidence interval as also observed by Rahman *et al*. (2015) in pumpkin. Similar results were also observed by several researchers Sereno *et al*. (2001); Pereira *et al*. (2004) and Eren and Kayamak-Ertekin (2007) in potato.

Influence of process conditions on solute gain and dehydration efficiency:

The p-values less than 0.0500 obtained by analysis indicate that temperature, time, concentration and interaction of temperature with time, interaction of temperature with concentration, interaction of time with concentration have significant effect on solute gain at 95 per cent confidence interval. Rahman and Lamb (1991) and Silva *et al*. (2012) also reported that rate of sucrose diffusion is a function of solute concentration and temperature. The quadratic model developed in coded form (at 95% confidence interval) excluding the non-signficant terms is presented as below:

$$\text{Solid gain} = +16.51-1.26*a-0.205*B-0.515*C-0.44*aB-0.503*aC-0.301*BC-0.604*a^2-0.485B^2+0.120C^2 \quad ....(5)$$

$$\text{Dehydration efficiency} = +3.99+0.640*a+0.218*B+0.431*C+0.217*aB+0.187*aC+0.150*BC+0.257*a^2+0.120B^2-0.013C^2 \quad ...(6)$$

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor co-efficients.

Influence of process conditions on water activity:

The p-values less than 0.0500 obtained by analysis indicate that temperature, time and concentration have significant effect on solute gain at 95 per cent confidence interval. The quadratic model developed in coded form (at 95% confidence interval) excluding the non-signficant terms is presented as below:

$$\text{Water activity} = +0.479-0.043*a-0.030*B-0.039*C-0.008*aB\ 0.003*aC+0.003*BC+0.015*a^2+0.010B^2+0.018C^2 \quad ....(7)$$

Influence of process conditions on texture:

The p-values less than 0.0500 obtained by analysis indicate that temperature, time and concentration have significant effect on solute gain at 95 per cent confidence interval. The effect of interaction of temperature with time, time with concentration also showed significant effect on texture of osmo-dried carrot slices. The quadratic model developed in coded form (at 95%

Table 1: Process variables and responses values for optimization

Name	Goal	Lower limit	Upper limit	Importance
a:Temperature	Is in range	30	60	3
B:Time	Is in range	4	8	3
C:Concentration	Is in range	50	70	3
Water loss	Maximize	56.42	75.16	3
Solid gain	Maximize	12.2	18.02	3
DE	None	3.13	6.16	3
aW	Minimize	0.42	0.62	3
Texture	Minimize	37.47	49.56	3

confidence interval) excluding the non-signficant terms is presented as below:

$$\text{Texture}=+44.86+2.61*a+1.48*B+3.00*C+0.55*aB-0.086*aC-0.428*BC-0.496*a^2-0.349B^2-0.652*C^2 \qquad ....(8)$$

Optimization:

The process conditions for osmo-dehydration of carrot slices were selected on the basis of numerical optimization using optimum values of process parameters and responses observed as shown in Table 1.

The numerical optimization is based on finding a point that maximizes the desirability function (Shafiq *et al.*, 2010). An equal improtance of 3 was given to all the process parameters and responses. The selected optimum condition for processing as given by model is 37.53^{0}C temperature, 6.9 hours time, 61.6 ^{0}B concentration which gives the best responses as 66 per cent water loss, 16.8 per cent solute gain, 3.8 DE, 0.49 aW and 44.40 N texture.

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