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OPTIMIZATION OF PROCESS VARIABLE FOR RTE OSMO-CONVECTIVELY DEHYDRATED CARROT SHREDS

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ABSTRACT

Background: RTE food is one of the alternatives to regular food due to its ultimate convenience so as to consume *any time-at any place*. The demand for these food products is increasing rapidly due to busy life style of the people. Carrot being nutritionally rich is becoming integral part of daily diet. Osmo-convective dehydration is one of the combo dehydration techniques to produce fruit and vegetable based RTE products. The different parameters of osmotic process have a prominent influence on quality of dehydrated products and hence need to evaluate the effect of process parameters on quality of dehydrated products.

Objective: The experiment was carried out to optimize the process parameters for the preparation of osmo-convective RTE carrot shreds using Response Surface Methodology.

Method: Box-Behnken design was applied for optimizing the process parameter of osmotic dehydration. Concentration and temperature of osmotic solution and process duration were investigated for water loss and solid gain during osmosis. Pre-blanched carrot shreds were osmo- convective dehydrated and analyzed for colour, hardness and overall acceptability. The process was optimized for maximum overall acceptance of osmo-convectively dehydrated carrot shreds.

Conclusion: The optimal conditions of process variable were concentration and temperature of osmotic solution of 48.58°B and 49.35°C respectively for 4.08 h process duration.

KEYWORDS: Osmatic dehydration, RTE carrots shreds, Optimization, Response Surface Methodology.

1. INTRODUCTION

Ready to Eat foods are ready for consumption without any additional heat treatment. Emergence and development of industries lead better emoluments to labor category and shortage of home maid-servants which made housewives essential to use RTC/RTE foods [1]. For fruit and vegetable based RTC and RTE products, dehydration is one of the prominent and economical technologies. It not only lowers the cost of packaging, storing and transportation but also have longer shelf life. Carrot is a fleshy, delicious and very attractive edible root crop. The widely used orange carrot is high in α and β-carotene and is a rich source of provitamin A besides appreciable amounts of vitamins B1, B2, B6 and B12 and minerals. Carotenoids in orange carrots are potent antioxidants which help to decrease risk of cancer and modulate immune response in human body [2, 3]. In India the production of carrot is 2640.96 MT in an area of 123.30 ha [4]. Carrot being a perishable and seasonal crop, it is not possible to readily make it available throughout the year. The inclusion of osmotic process in conventional dehydration has additional benefits of quality improvement and energy savings [5, 6].

Osmotic dehydration of carrot during the main growing season is one of the important alternatives for the production of RTE carrot products. Pretreatments like blanching, freezing and thawing before osmosis plays an important role on mass transfer kinetics during osmotic dehydration of fruits and vegetables [7, 8]. Blanching apart from enzyme inactivation minimizes the membrane resistance to cell membrane with minimum damage and promotes mass transfer phenomenon. Freezing also increases the permeability of the cells and enhances mass transfer during osmotic process [9, 10, 11]. The influence of the main process variables, such as concentration, composition and temperature of osmotic solution, immersion time, pretreatments, agitation, fruit structure, size, shape, geometry, solution to sample ratio are the main parameters that have influence on rate of mass transfer and ultimately on the quality of product [7, 12, 13]. Osmotic parameters such as concentration and temperature of osmotic solution and immersion time are dominating factors for mass transport phenomenon. Effect of these parameters on mass transport kinetics is dependent and affected by size and shape of the sample. Also, the levels of process variables are very influencing for obtaining better quality *Ready to Eat* osmo-dehydrated products. Therefore, an experiment was carried out to prepare the osmo- convectively dehydrated carrot shreds and to optimize the process parameters for osmotic dehydration.

2.MATERIALS AND METHODS

2.1 Preparation of samples

Fresh, fully grown, firm and deep orange-coloured carrots were procured from the local market. The preliminary trials were conducted to assess the effect of different pretreatments such as blanching, freezing and thawing on overall quality of osmo-convectively dehydrated carrot shreds. Based on previous research work for carrot and various fruits/vegetables, parameters for blanching, freezing and thawing were considered for experiment [14, 15]. Pretreatment of 2 min. steam blanching resulted in desirable overall acceptance. Hence carrot shreds were steam blanched for 2 minutes before osmotic dehydration [16, 17, 18]. For each experiment known weight of carrot shreds were put in a glass beaker containing the sugar syrup. A ratio 1:4 (w/v) of carrot shreds to osmotic solution was kept constant for all the trials [19, 20, 21, 22]. A uniform temperature was maintained during osmosis by agitating the hot water bath. Concentration and temperature of osmotic solution and immersion time were selected as per experimental design. Agitation was used to reduce the mass transfer resistance at the surface of the carrot shreds and to maintain the temperature uniformly in the osmotic medium [2, 23, 24]. During experimentation, it was assumed that the amount of solid leaching out of carrots during osmosis was negligible [2, 25, 26]. Osmotically dehydrated carrot shreds were dried in hot air dryer at 60^0 C air temperature up to moisture content of 5± 0.5 % (wet basis).

2.2 Experimental Design and Statistical Analysis

Response surface methodology (RSM) was applied to assess the effects of osmotic dehydration process parameters on various responses i.e. water loss, solid gain, texture, colour and sensory score. A Box-Behnken of Response surface methodology is used to model and optimize selected process variable with three process factors and three levels [27]. Design consisted total seventeen experimental runs with five replicates at center points. Three different levels for each experiment in coded form are -1, 0 and 1.

$$\text{Coded values } X = X_i - X_o / \Delta X \qquad \text{--------------- Eq. 1}$$

Where, X is the coded value, X_i is the corresponding actual value, Xo is the actual value in the center of domain, and ΔX is the increment of X_i corresponding to a variation of 1 unit of X. The natural and coded values of independent variables are presented in Table 1.

Table 1. Levels of independent variables for osmotic dehydration of carrot shreds

Coded levels	Uncoded values of process variables		
	Concentration(°B)	Time (h)	Temperature (°C)
-1	40	3	40
0	50	4	50
1	60	5	60

Low and high level in uncoded/actual form were taken as 40-60 °Brix, and 40-60 °C for concentration and temperature of osmotic solution respectively, whereas immersion time was 3-5 hour [28, 2, 9, 29, 30, 31]. The experimental design along with the values of various independent variables and responses variables is given in Table 2. The second order polynomial equation was fitted to describe the relationship between responses and independent variables (Eq. 2).

$$Y_k = \beta_{ko} + \sum_{i=1}^{i=3} \beta_{ki} x_i + \sum_{i=1}^{i=3} \beta_{kii} x_i^2 + \sum_{i=1}^{i=2} \sum_{j=i+1}^{j=3} \beta_{kij} x_i x_j \qquad \text{------------- Eq. 2}$$

Where, Y represents the response variable, Xi and Xj are the independent; βko, βki, βkii and βkij are regression coefficients for intercept, linear, quadratic and interaction term. Analysis of variance (ANOVA) was used in order to evaluate model adequacy and determine regression coefficients and statistical significance [32]. Response Surface Methodology (Design-Expert version 8.0.6, Stat- Ease Inc. Minneapolis, USA, trial version) was used for regression analysis of experimental data and to optimize the process parameters. Experimental data were fitted to the second order polynomial model and regression coefficients obtained. The model was simplified by dropping terms which were statistically insignificant ($p>0.05$) by means of analysis of variance (ANOVA). Optimization of independent variables for osmotic dehydration of carrot shreds was determined to find levels of independent variables namely concentration and temperature of osmotic solution, immersion time which would give maximum overall acceptance (sensory score) of RTE carrot shreds [33, 2, 34].

2.3 Determination of Response Variables

Moisture content of carrot shreds after osmosis, mass transfer parameters (water loss (WL), solids gain (SG)) were determined to assess the effect of process parameters on response variables [35, 36]. The textural property (hardness) of RTE carrot shreds were determined by measuring the force (Kg) needed to compress the RTE carrot shreds using Texture Analzer (Model: TA-XT plus, Stable Micro System, UK)l. The redness of RTE carrot shreds was evaluated using a Hunter Lab Colour Analyzer-Labscan-2 (Hunter Associates Laboratory, Inc. Virginia, USA) in terms of colour value a*. Sensory evaluation of RTE carrot shreds was carried out using a 9-point hedonic scale. Overall acceptability was determined by considering the sensory scores of colour, appearance, texture, taste and favour of final product.

3. RESULT AND DISCUSSION

The Box-Behnken model was applied to assess the changes in water loss, solid gain, hardness, colour and overall acceptability of RTE carrot shreds. The influence of the process parameter Concentration (40-60°B) and temperature (40-60°C) and immersion time of (3-4 h) on investigated responses (solid gain, water loss, hardness, colour and overall acceptability) was optimized using response surface methodology and the data is presented in Table 2.

Model fitting

Experimental results were fitted to second order polynomial model and multiple regression coefficient were generated for all responses. The results of analysis of variance (ANOVA) and regression coefficient along with their statistical significance for every response were investigated and presented in Table 3 and 4. The goodness of the fit of the model with the data was assessed using the coefficient of determination (R^2) which was calculated through least square technique. The R^2 values for all the response variables were higher ($R^2 > 0.900$) and relatively low CV <10% indicating an excellent fit of models to the experimental data. Moreover, the F values of lack of fit were non-significant for all the investigated responses suggesting the suitability of developed model for predicting the response variable adequately during osmotic dehydration of RTE carrot shreds. For almost all effect of process parameters on response variable of osmotic process of RTE carrot shreds have the p values ($p < 0.05$) which indicate the significance of analysis at 95.0% confidence level. The regression equations describing an influence of process variable on the response variable in terms of its coded value and estimated coefficients are represented in Table 5 and 6 [37].

Table 2: Experimental design and experimental data for osmotic dehydration of RTE carrot shreds

Coded Variables			Uncoded Variables			Responses				
Solution Concentration (°B)	Solution Temperature (°C)	Immersion Time (h)	Solution Concentration (°B)	Solution Temperature (°C)	Immersion Time (h)	Water Loss (%)	Solid Gain (%)	Hardness (N)	OA	Colour a* value
-1	-1	0	40	40	4	15.35	31.23	2.285	7.3	26.72
1	-1	0	60	40	4	28.37	36.94	8.551	6.9	32.98
-1	1	0	40	60	4	26.82	35.26	4.564	7.9	24.05
1	1	-1	60	60	4	34.05	46.56	9.239	6.1	29.05
-1	0	-1	40	50	3	17.04	31.66	3.561	7.7	23.06
1	0	-1	60	50	3	25.97	37.28	8.739	7.5	29.18
-1	0	1	40	50	5	19.57	37.07	3.969	8.2	25.02
1	0	1	60	50	5	30.12	43.16	9.761	6.5	29.82
0	-1	-1	50	40	3	16.37	32.87	5.736	8.1	28.72
0	1	-1	50	60	3	25.02	37.96	7.456	8.2	24.35
0	-1	1	50	40	5	20.15	34.99	6.657	8.3	29.49
0	1	1	50	60	5	28.20	44.84	8.013	7.9	25.52
0	0	0	50	50	4	23.54	35.19	6.945	8.5	30.19
0	0	0	50	50	4	23.16	36.94	6.754	8.9	29.77
0	0	0	50	50	4	23.59	37.14	7.045	8.8	28.59
0	0	0	50	50	4	22.84	36.66	7.0257	9.1	29.72
0	0	0	50	50	4	24.02	37.04	6.852	8.9	29.84

Water Loss

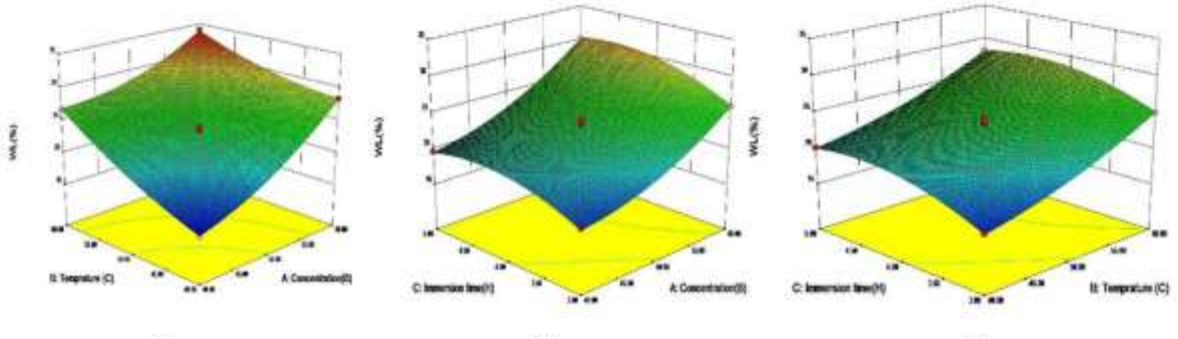
The statistical analysis and the p-value (Table 3) indicated the significance of linear and its interaction terms on water loss. The recorded value of water loss exhibited considerable variation ranging from 15.35 to 34.05 % across experimental treatments. Coefficient β of regression model revealed the maximum positive effect of concentration and immersion time on water loss followed by temperature of sugar syrup during osmosis process. However water loss is greatly affected osmotic solution concentration than temperature of solution. A gradual increase in water loss with higher concentration and temperature of osmotic solution was primarily due to an augmented osmotic pressure gradient. An increase in temperature resulted in reduction in viscosity of the osmotic solution, thus diminishing external resistance to mass transfer at the product's surface [29, 38, 39]. This reduction in resistance facilitates the outflow of water through the cellular membrane and resulted in enhanced water loss [7]. It was also observed that the water loss increased linearly with immersion time. Similar results were observed during osmo-dehydration of papaya cubes and pineapple slices [31, 40].

Table 3 : Regression summary and ANOVA for water loss, solid gain and hardness of RTE carrot shreds.

		Water Loss (%)				Solid Gain (%)				Hardness (N)			
Source	**Df**	**Sum of Squares**	**Mean Squares**	**F-value**	**p-value**	**Sum of Squares**	**Mean Squares**	**F-value**	**p-value**	**Sum of Squares**	**Mean Squares**	**F-value**	**p-value**
Model	9	404.65	44.96	343.58	<0.0001	286.18	31.80	63.15	< 0.0001	68.21	7.58	864.23	< 0.0001
X1-Concentration	1	197.31	197.31	1507.78	<0.0001	125.77	125.77	249.78	< 0.0001	60.01	60.01	6843.20	< 0.0001
X2-Temprature	1	143.23	143.23	1094.51	<0.0001	102.17	102.17	202.92	< 0.0001	4.56	4.56	520.52	< 0.0001
X3-Immersion	1	23.26	23.26	177.72	<0.0001	37.37	37.37	74.21	< 0.0001	1.06	1.06	120.54	< 0.0001

Time													
X_1X_2	1	8.38	8.38	64.05	<0.0001	7.81	7.81	15.52	0.0056	0.63	0.63	72.16	< 0.0001
X_1X_3	1	0.66	0.66	5.01	0.0602	3.01	3.01	5.98	0.0444	0.094	0.094	10.75	0.0135
X_2X_3	1	0.090	0.090	0.69	0.4343	5.66	5.66	11.25	0.0122	0.033	0.033	3.78	0.0931
X_1^2	1	12.58	12.58	96.16	<0.0001	0.050	0.050	0.10	0.7607	1.57	1.57	179.42	< 0.0001
X_2^2	1	4.12	4.12	31.46	0.0008	4.32	4.32	8.58	0.0220	0.099	0.099	11.28	0.0121
X_3^2	1	16.57	16.57	126.62	<0.0001	0.014	0.014	0.028	0.8715	0.16	0.16	18.16	0.0037
Residual	7	0.92	0.13			3.52	0.50			1.878E-003	8.770E-003		
Lack of fit	3	0.11	0.036	0.18	0.9044*	0.93	0.31	0.48	0.7139*	0.063	6.261E-004	0.042	0.9869*
Pure Error	4	0.81	0.20			2.59	0.65			68.27	0.015		
Cor Total	16	405.57				289.71				289.71			
R²		0.9977				0.9878				0.9991			
Adjusted R²		0.9948				0.9722				0.9979			
Predicted R²		0.9926				0.9345				0.9982			
CV%		1.52				1.92				1.41			

* - Non Significant

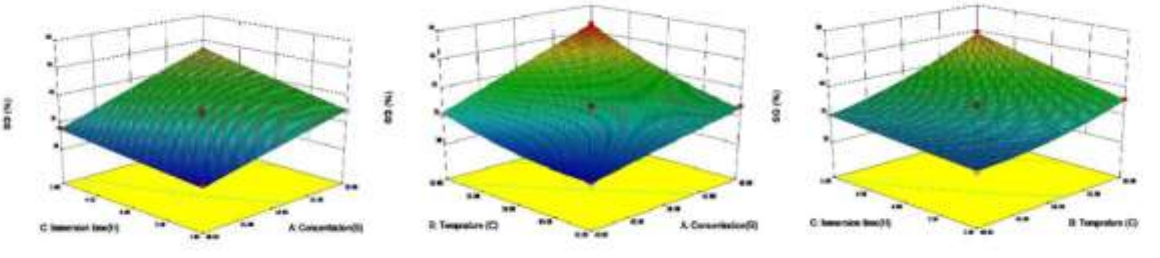


(A) (B) (C)

Fig. 1: The effect of osmotic solution temperature, concentration and immersion time on water loss during osmotic dehydration

Solid gain

The effect of all process variables was significant at linear, interaction and quadratic terms except quadratic term of concentration. The R^2 value for sugar gain was 0.9878, signifying a strong alignment between the model and the data. The model exhibited a significant F value of 63.25 for solid gain with a p-value (< 0.0001). The coefficients of the process variables (Table 5) indicated a positive influence of these variables on solid gain which revealed that syrup concentration had the most substantial impact on sugar gain, than the temperature of the syrup and immersion time. The increase in solid gain with increased concentration (Fig. 2(A-C)) was due to a higher osmotic pressure gradient affecting the cell membrane functionality to permit sugar more readily into the sample tissue. An augmented mass transfer of sugar molecules with an increased concentration of solution was noted primarily due to the swelling effect on the membrane, which also accelerated mass transport in orange slices and mango [41, 42, 7].



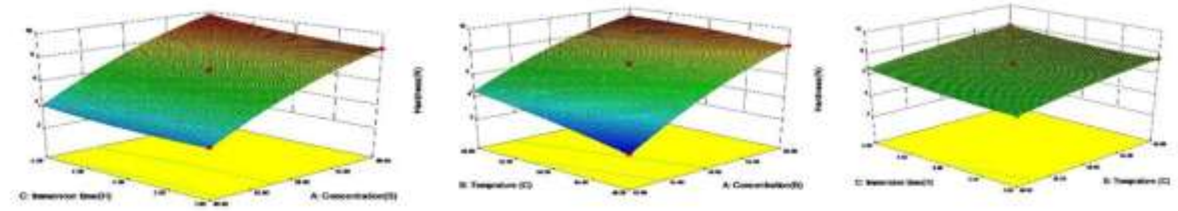
(A) (B) (C)

Fig. 2: The effect of sugar solution temperature, concentration and immersion time on solid gain during osmotic dehydration

Elevated sugar gain with increase in temperature may be attributed to enhance the permeability of the cell membrane, allowing solutes to penetrate more effectively. A decrease in the viscosity of the osmotic solution at higher temperatures was observed influencing solid gain positively. The reduced viscosity resulted in the reduction in resistance to the diffusion of solutes into the sample tissue [43].

Hardness

The significant linear and interaction effect was indicated for all the process variables while some interaction and quadratic terms were non-significant. The model exhibited its significance with a very low p-value ($P < 0.0001$) and R^2 0.9991 for hardness, indicating an excellent fit of the model to the data. The β coefficients of regression equation reflected into a pronounced effect of concentration of osmotic solution on hardness during osmo-convective dehydration compared to solution temperature. Higher solution temperatures were resulted in increased hardness (Fig. 3 A and B). Similar findings have been reported for candied pumpkin and osmo-dehydrated yellow carrot slices due to an enhanced mass transfer phenomenon which exhibited a more compact structure [44, 45].

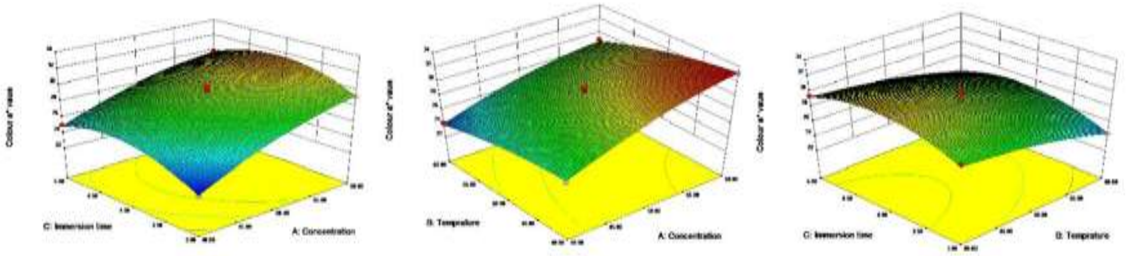


(A) (B) (C)

Fig. 3: The effect of osmotic solution temperature, concentration and immersion time on hardness of RTE carrot shreds.

Colour value a*

The color value a*represents the redness of ready-to-eat (RTE) carrot shreds, which reflects the attractive appearance of product (23.06 to 30.19). R^2 value standing at 0.9838 reflects a strong fit of the model to the data. The coefficients of the process variables (Table 5) revealed that the osmotic solution concentration had more pronounce effect followed by the solution temperature, while the process duration had non- significant effect on the color value a*. It was observed that color value a* of carrot shreds decreased with an increase in sugar syrup concentration and solution temperature (Fig 4 A). The decrease in redness with increased sugar gain is in line with findings reported for osmo-dehydrated carrot cubes in mixtures of sucrose and sodium chloride solutions [2]. The pronounced color alteration was reported in osmo-dehydrated cherry tomatoes primarily due to increased water loss at high temperature [47].



(A) (B) (C)

Fig. 4: The effect of osmotic solution temperature, concentration and immersion time on colour value a* of RTE carrot shreds

Overall acceptability

Consumer acceptance of food products is critically influenced by overall acceptability. The range of overall acceptability score of ready-to-eat (RTE) carrot shreds is within the range of 6.1 to 9.1.

Table 4: Regression summary and ANOVA for overall acceptability and colour value a* of RTE carrot shreds

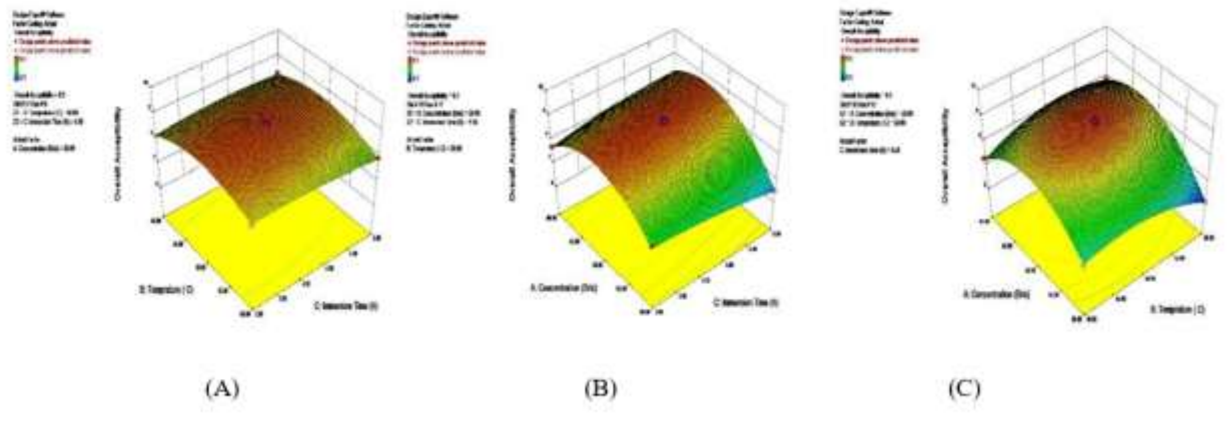
		Overall acceptability				Colour value a*			
Source	**Df**	**Sum of Squares**	**Mean Squares**	**F Value**	**p- Value**	**Sum of Squares**	**Mean Square**	**F-value**	**p-value**
Model	9	11.51	1.28	39.88	<0.0001	116.05	12.89	47.16	<0.0001
X1-Concentration	1	2.10	2.10	65.52	<0.0001	61.49	61.49	224.90	<0.0001
X2-Temperature	1	0.031	0.031	0.97	0.0565	27.90	27.90	102.04	<0.0001

X_3-Immersion Time	1	0.045	0.045	1.40	0.0749	2.58	2.58	9.42	0.0181
X_1X_2	1	0.49	0.49	15.28	0.0058	0.40	0.40	1.45	0.2674
X_1X_3	1	0.56	0.56	17.54	0.0041	0.44	0.44	1.59	0.2473
X_2X_3	1	0.062	0.062	1.95	0.0054	0.040	0.040	0.15	0.7135
X_1^2	1	6.27	6.27	195.41	<0.0001	2.94	2.94	10.76	0.0135
X_2^2	1	1.37	1.37	42.65	0.0003	1.45	1.45	5.29	0.0550
X_3^2	1	0.089	0.089	2.76	0.0406	17.11	17.11	62.58	<0.0001
Residual	7	0.22	0.032			1.91	0.27		
Lack of fit	3	0.032	0.011	0.23	0.8743*	0.45	0.15	0.41	0.7571*
Pure Error	4	0.19	0.048			1.47	0.37		
Cor Total	16	11.74				117.96			
R²		0.9809				0.9838			
Adjusted R²		0.9563				0.9629			
Predicted R²		0.9301				0.9199			
CV%		2.26				1.87			

* - Non Significant

The developed model was sufficient (R^2 value, 0.9809) for predicting overall acceptability during the osmotic dehydration. There was maximum negative significant contribution of syrup concentration (Table 5) on overall acceptability (%) of RTE carrot shreds where as duration and temperature individually exhibited minor effect on overall acceptability. Specifically, the quadratic term related to the concentration of the sugar solution had the most pronounced negative effect, followed by the quadratic term associated with the temperature of the osmotic solution, on the overall acceptability (%) of RTE carrot shreds. A similar trend was reported for overall acceptability of osmo-dehydrated carrot cubes in a mixture of sugar and salt solution [30].

The negative coefficients associated with linear, interaction, and quadratic terms indicated that both excessive increases and decreases in the levels of these variables led to a decrease in the overall acceptability of RTE carrot shreds. It might be due to associated higher and lower values of solid gain affecting the taste, appearance and texture of RTE carrot shreds.



(A) (B) (C)

Fig. 5 : The effect of sugar solution temperature, concentration and immersion time on overall acceptability of RTE carrot shreds.

Table 5: Second order polynomial equations with neglected insignificant coefficients for response variables

Response	Second-order polynomial model equation
Water Loss	$Y=23.43+4.97X_1+4.23X_2+1.71X_3+1.73X_1^2+0.99X_2^2-1.98X_3^2$
Solid gain	$Y=+36.59+3.96X_1+3.57X_2+2.16X_3+1.40X_1X_2+0.87X_1X_3+1.19X_2X_3-0.11X_1^2+1.01X_2^2+0.058X_3^2$
Hardness	$Y=+6.92+2.74X_1+0.76X_2+0.36X_3$
Colour value a*	$Y=+29.62+2.77X_1-1.87X_2+0.57X_3-0.32X_1X_2-0.33X_2X_3+0.100X_2X_3$
Overall acceptability	$Y=+8.84-0.51X_1-0.062X_2-0.075X_3-0.35X_1X_2-0.37X_1X_3-0.12X_2X_3-1.22X_1^2-0.057X_2^2-0.14X_3^2$

Table 6: Estimated coefficients of the fitted second-order polynomial models for all response variables

Regression coefficients	Water Loss	Solid gain	Hardness	Colour value a*	Overall acceptability
β_o	23.43	36.59	6.92	29.62	8.84
Linear					
β_1	+4.97	+3.96	+2.74	+2.77	-0.51
β_2	+4.23	+3.57	+0.76	-1.87	-0.062
β_3	+1.71	+2.16	+0.36	+0.57	-0.075
Interactions					
β_{12}	-1.45	+1.40	-0.40	-0.32	-0.35
β_{13}	+0.41	+0.87	+0.15	-0.33	-0.37
β_{23}	-0.15	+1.19	-0.091	+0.100	-0.12
Quadratic					
β_{11}	+1.73	-0.11	-0.61	-0.84	-1.22
β_{22}	+0.99	+1.01	-0.15	-0.59	-0.057

Optimization

Optimizing the process variables for osmotic dehydration was required to achieve higher sensory acceptance of osmo-convectively dried ready-to-eat (RTE) carrot shreds. Sugar gain played a pivotal role in affecting other sensory parameters including color, appearance, flavor, texture, and taste. The primary criterion for optimization was to achieve the highest possible score for overall acceptability of ready-to-eat (RTE) carrot shreds.

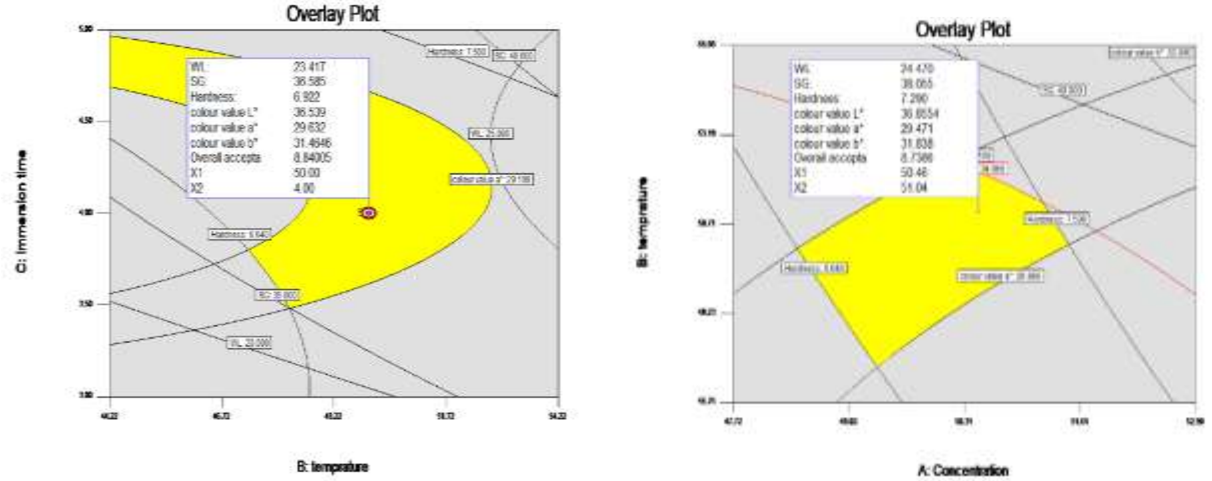


Fig. 6: The superimposed contour plots for RTE carrot shreds at varying
(A) Immersion time and temperature
(B) Concentration and temperature of osmotic solution

Superimposed contour plots having common superimposed area for all responses shown in fig 5. The points in the range of osmotic solution concentration 49.58 °B solution temperature 49.35 °C and 4.08 h immersion time were optimum for osmotic dehydration. Corresponding to these optimum conditions, predicted value for water loss 22.59 %, solid gain 35.97 %, hardness 6.5 N, colour value a* 29.36 and overall acceptability 8.88.

CONCLUSION

High correlation coefficient obtained during analysis proved the suitability of model to predict water loss, sugar gain and overall acceptability of RTE carrot shreds under different osmotic condition. Optimum solution obtained by numerical optimization was 49.58 °B sugar concentration, 49.35°C temperature of sugar solution and 4.08 h of process duration to get desirable water loss, solid gain, hardness, colour value a* and maximum overall acceptability of osmo-convectively dehydrated RTE carrot shreds.

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