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Osmotic dehydration of radish for improving nutritional value

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Abstract
The study was proposed for preparing value added product from radish so as to increase its overall consumer acceptability and storability. Minimal processing technique i.e., osmotic dehydration of radish was carried out for preparing radish cubes. Response surface methodology (RSM) and Box-Behnken design was used for optimizing input parameters. The fresh white radish was used for this investigation. The Box- Behnken design of three variables and three levels including 17 experiments formed by 5 central points was used for optimizing input parameters. The effect of sugar concentration (40, 50 and 60°B), osmotic temperature (40, 50 and 60 °C), fruit to syrup ratio (1:5) and duration of osmosis (120, 180 and 240 min) were studied during osmotic dehydration. With respect to water loss, solid gain, mass reduction and colour (L) the linear, quadratic and interaction effects of three variables were analysed. For each response, second order polynomial models were developed using multiple regression analysis. Analysis of variance (ANOVA) was performed to check the adequacy and accuracy of the fitted models. The superimposed graph recorded the optimum process parameters i.e., syrup temperature 52.47 °C, sugar concentration 40°B and duration or time 238.57 min for determined the various responses i.e., 53.34% water loss, 8.45% sugar gain and 80.66 colour (L). Results of validation tests were highly acceptable since the coefficient of Regression Coefficient (R greater than 0.98) and coefficient of variation (CV<5%) of the responses.

Keywords: Radish cubes, osmotic dehydration, nutritional value, water loss and sugar gain

Introduction

Vegetables are an important component of daily diet and the nutritional value of vegetables as a vital source of micronutrients has been well recognized. Radish cannot be stored more than 2-3 day as it is highly perishable in nature. To avoid the huge wastage, the surplus could be processed and preserved properly by converting the produce into value added product. To prepare value added product with best consumer acceptable quality and maximum nutritional value it is necessary to convert the produce into value added form by minimal processing. The shelf life of the products may be improved by using either dehydration, canning or refrigeration process thus, enhancing the storability of the product. Dehydrated vegetable products have inherent advantages, such as prolong shelf life, higher degree of resistance to bacterial attack and lower transportation, handling and storage. One effective method for reducing this huge loss would be osmo-convective dehydration.

Osmotic dehydration (OD) is an important technique of food preservation and processing in which foods especially fruits and vegetables are immersed in the osmotic solution containing concentrated salt, sugar, alcohol or starch. The osmotic agent used may be fructose, corn syrup, glucose, sodium chloride or sucrose. The dehydration occurs primarily due to an osmotic water flow and solute activity gradients across the semi permeable membranes. Osmotic dehydration is a simultaneous diffusion process which benefits the finished product by reducing the damage due heat also help to maintain its flavour, colour, inhibits the browning of enzymes and decreases the energy costs when comparing to other conventional methods. Osmotic dehydration process is a simple procedure which requires decreased cost and energy consumption. It is easy to perform at room temperature, which ensures the retention of colour, texture and nutrients. Osmotic dehydration process also involves limited loss of volatile compounds and less oxidative changes.

The present study is based on osmotic dehydration of radish cubes which involves two stages process where, the water is removed using an osmosis process and subsequent dehydration of radish cubes is carried out for further improving the shelf life of the product for better storability and overall consumer acceptability.

Objectives of the present investigation were to study osmotic dehydration behaviour and optimized the process parameters for osmotic dehydration of radish cubes.

Materials and Methods

Procurement of Raw Material

Fresh white radish was purchased from local market and then water washed, peeled and used for different experiments.

Solution Preparation and Experimental procedure

Radishes were washed, cleaned from dirt, peeled using knife, sliced and cut into cubes to required 10 mm^3size. The size reduced radish is then weighed to 30 gm to standardize the amount required for various treatments of the study. Sugar was used as an 'osmotic agent'. The syrup was prepared by dissolving required amount of sugar in distilled water. The sample to syrup ratio 1:5 was kept as constant treatment. In the process of osmotic dehydration, a sample placed in the solution and due to concentration difference water comes out from the sample to solution. Simultaneously transport of solids takes place from the solution to sample and vice versa. As an osmotic dehydration unit, a small capacity laboratory temperature-controlled water bath measuring 68 x 31 x 35 cm (Approximate capacity, 10 litres) was used. In the investigation, the temperature controller was employed to maintain the desired temperature

The mass transport in terms of water loss, mass reduction and solid gain were studied as explained below.

Water loss (WL)

$$WL = \frac{W_{si}X_{swi} - W_{s\theta}X_{sw\theta}}{W_{si}}$$

Mass reduction (WR)

$$WR = \frac{W_{si} - W_{s\theta}}{W_{si}} \times 100$$

Solid gain (SG)

$$SG = \frac{W_{si}(1 - X_{sw\theta}) - W_{si}(1 - X_{swi})}{W_{si}} \times 100$$

SG=WL-WR

where,

WL = water loss (g water per 100 g initial mass of sample)

WR = mass reduction (g mass per 100 g initial mass of sample)

SG = solid gain (g solids per 100 g initial mass of sample)

Wsi = initial mass of sample, g

Wsθ = mass of the sample after time θ, g

Xwi = water content as a fraction of the initial mass of the sample and,

Xswθ = water content as a fraction of the syrup at time θ.

Targeted Sugar content in radish cube

As a result, given the significance of sugar gain in product quality, acceptability, and marketability of osmo-convectively dried products, this element was used as a targeted constraint for optimising the osmotic dehydration input parameters. It was necessary for this to be done. For this purpose, the experimental run as given below followed by convective drying was used to evaluate the product quality by sensory evaluation.

Colour measuring digital chromameter was used to measure the colour (L value). To measure colour, a high-revolution digital camera was used to capture a colour image of the sample and directly gives value of L*, a* and b*.

The variables of osmotic dehydration process were optimised using RSM technique. Because RSM is a valuable statistical tool for investigating complex processes, the variables of the osmotic dehydration process were optimised using it. The experimental design along with values of various responses is given in the Table 2. The Box Behnken design was utilised, with three variables and three levels, and 17 trials formed by five centre points. To perform this operation, Design expert version 13 of the STAT- EASE software (Statease Inc, Minneapolis, USA, Trial version), was used for simultaneous optimization of the multiple responses.

Table 1: Levels of independent variables for osmotic dehydration of radish cubes

Independent variables	Symbols		Levels	
	Coded	Un-coded	Coded	Un-coded
Syrup Concentration (°B)	X1	C	1	60
			0	50
			-1	40
Syrup Temperature (°C)	X2	T	1	60
			0	50
			-1	40
Osmosis Duration	X3	θ	1	240
			0	180
			-1	120

The exact mathematical form of the function (f) is either unknown or extremely difficult to figure out. The response, $Y_k$and the factors, x_i were thought to be related by a second order polynomial equation of the following kind.

$$Y_k = \beta_{ko} + \sum_{i=0}^{i=3} \beta_{ki} \sum_{i=0}^{i=3} \beta_{ki}\, x_i + \sum_{i=0}^{i=3} \beta_{ki}\, {x_i}^2 + \sum_{i=0}^{i=3} \beta_{ki}\, x_i x_j$$

where Y_k is the response (i.e., water loss or sugar gain) $x_i$and $x_j$are the coded independent variables that are linearly related to C, T, and θ. β_{ko}, β_{kij} and β_{ki} are constant coefficients, and x and X are the coded independent variables that are linearly associated to C, T, and θ.

Results and Discussion

From the analysis indicated that the product with 8.45% sugar gain was most liked by the judges. The highest sensory score attributed to the product indicated that osmo-convectively dried radish cubes having 8.45% sugar gain may acquire higher liking by the consumer. Therefore, the input parameters, namely, syrup temperature, syrup concentration and duration of osmosis were optimized on the basis of maximum water loss and targeted sugar gain (8.45%).

ANOVA was used to assess the effect of variables on the responses. The results obtained in the form of ANOVA are given in table.

Table 2: Outline of the experimental design and observed values of responses

Treatment No.	Syrup conc., °B	Syrup temp., °C	Duration of osmosis, min	Water loss, %	Sugar gain, %	Mass Reduction %	Colour (lightness)
1	40	40	180	41.10	6.17	34.93	76.15
2	60	40	180	51.74	9.24	42.50	74.26
3	40	60	180	44.53	6.93	37.60	66.51
4	60	60	180	54.66	9.13	45.53	54.52
5	40	50	120	37.79	5.66	32.13	71.12
6	60	50	120	45.59	7.93	37.66	60.02
7	40	50	240	46.99	7.23	39.76	66.81
8	60	50	240	59.40	9.74	49.66	58.54
9	50	40	120	40.13	5.87	34.26	84.91
10	50	60	120	42.62	7.06	35.56	72.54
11	50	40	240	52.19	8.13	44.06	80.73
12	50	60	240	56.88	9.05	47.83	65.07
13	50	50	180	45.20	7.87	37.33	69.03
14	50	50	180	45.20	7.87	37.33	68.46
15	50	50	180	45.20	7.87	37.33	66.49
16	50	50	180	45.20	7.87	37.33	71.00
17	50	50	180	45.20	7.87	37.33	68.09

Effect of Process variable on Water loss (WL)

The variation in water loss by changing syrup temperature, syrup concentration and osmosis duration has been presented in Table 2. A second order polynomial Eqn. was fitted with the experimental data presented in Table 3 gives the predicted water loss, % as a function of syrup temperature (A), syrup concentration (B) and duration of osmosis (C) expressed in coded form.

Applying the RSM method, as per proposed suggestion for the purpose of fitting experimental data the quadratic model was used. The quadratic model was fitted to the experimental data and statistical significance for linear, quadratic and interaction terms was calculated for water loss as shown in Table 3. The R^2 value was calculated by least square technique and found to be 0.9884 showing good fit of model to the data. The model F value of 66.40 implies that the model is significant (p<0.0001). The linear terms (A, B and C) are significant (p<0.0001). The lack of fit F value was non-significant which indicated that the developed model was adequate for predicting the response. Moreover, the predicted R^2 of 0.9884 was in reasonable agreement with adjusted R^2 of 0.9735. This revealed that the non-model significant terms have not been included in the model. Therefore, this model could be used to navigate the design space.

Table 3: Anova for water loss during osmotic dehydration of radish cubes

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	574.85	9	63.87	66.40	< 0.0001	significant
A-Temperature	209.92	1	209.92	218.22	< 0.0001	
B-Sugar syrup concentration	22.88	1	22.88	23.79	0.0018	
C-Duration	304.18	1	304.18	316.21	< 0.0001	
AB	0.0650	1	0.0650	0.0676	0.0024	
AC	5.31	1	5.31	5.52	0.0511	
BC	1.21	1	1.21	1.26	0.0991	
A^2	7.30	1	7.30	7.59	0.0283	
B^2	14.09	1	14.09	14.64	0.0065	
C^2	6.73	1	6.73	6.99	0.0332	
Residual	6.73	7	0.9620			
Lack of Fit	1.49	3	0.4983	0.3804	0.7733	not significant
Pure Error	5.24	4	1.31			
Cor Total	581.58	16				

**Significant at 1% level, Significant at 5% level, NS-Non significant

Std. Dev.	0.9808	R^2	0.9884
Mean	46.94	Adjusted R^2	0.9735
C.V. %	2.09	Predicted R^2	0.9448
		Adeq Precision	30.0139

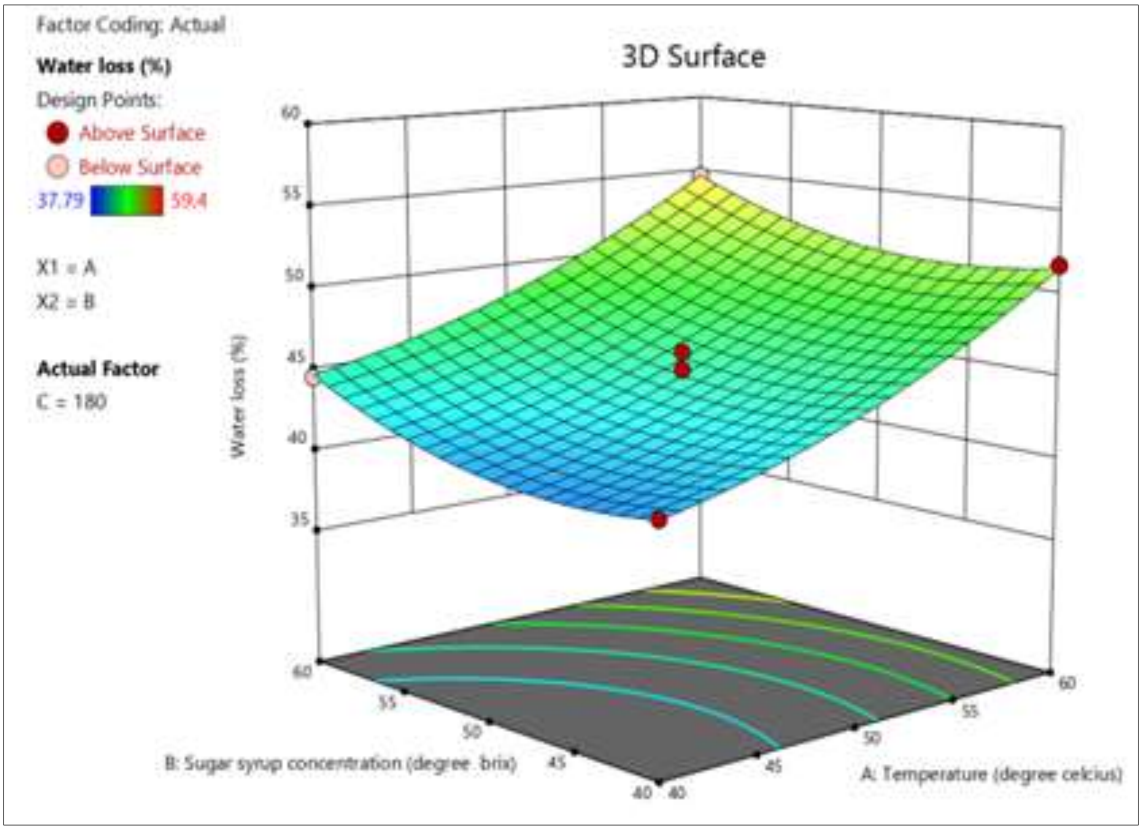
High value of coefficient of determination (R^2 = 0.9884) obtained for response variable indicated that the developed model for water loss accounted for and adequately explained 98.84% of the total variation. The result of analysis of variance indicated that the linear terms of syrup temperature, syrup concentration and duration of osmosis were highly significant at 1% level (Table 3). The presence of quadratic terms of concentration of syrup and duration of osmosis indicated curvilinear nature of response surface.

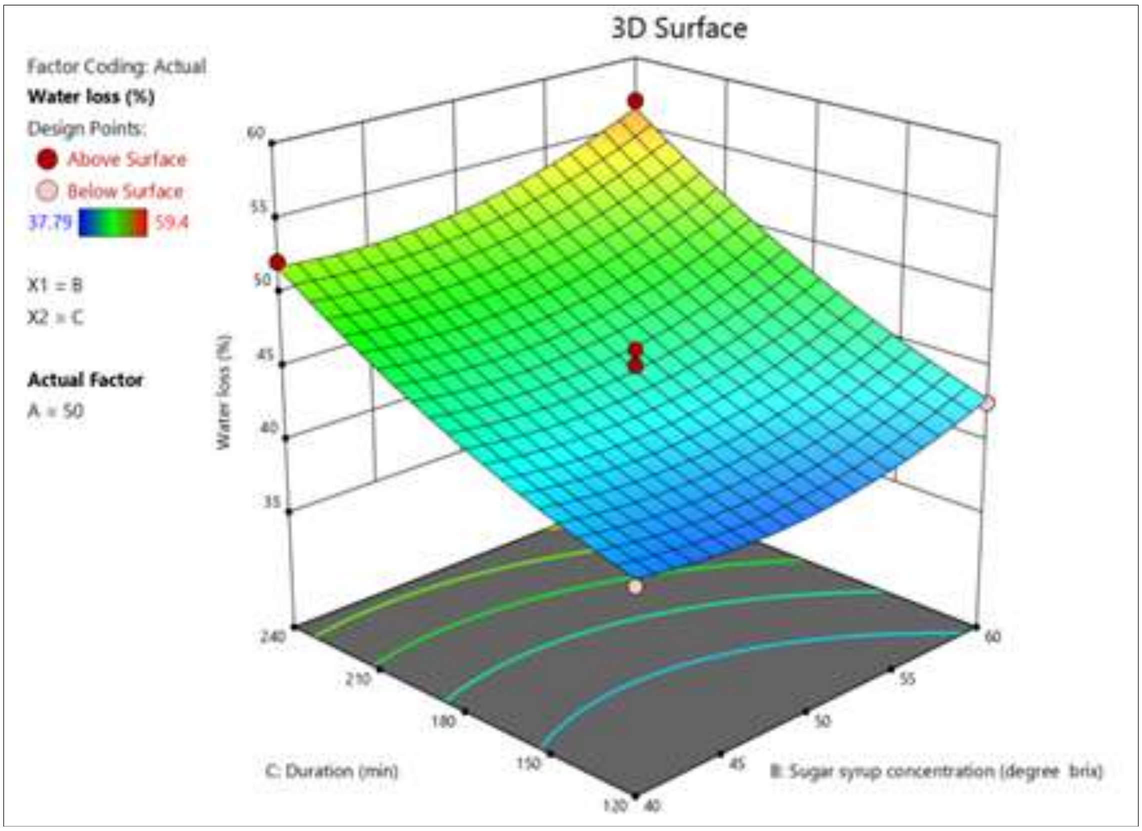
The comparative effect of each factor on water loss was observed by the F values in the ANOVA (Tables 3) and also by the magnitudes of coefficients of the coded variables. The F values indicated that concentration of syrup was the most influencing factor followed by duration of osmosis and temperature of syrup was least effective over water loss.

To visualize the combined effect of two variables on the water loss, the response surface and 3D surface (Fig. 1) were generated for the fitted model as a function of two variables while keeping third variable at its central value. The water loss increased rapidly in the early stages of osmosis, after which the rate of water loss from radish cubes into sugar syrup gradually slowed down with time. Rapid removal of water in early stages of osmosis has been reported for carrots (Uddin *et al*., 2004) [13], etc.

The higher temperatures seem to promote faster water loss through swelling and plasticizing of cell membranes as well as the better water transfer characteristics on the product surface due to lower viscosity of the osmotic medium.

The water loss increased with concentration of syrup as well as with duration of osmosis over the entire osmotic dehydration process. In the osmosis of other fruits and vegetable.





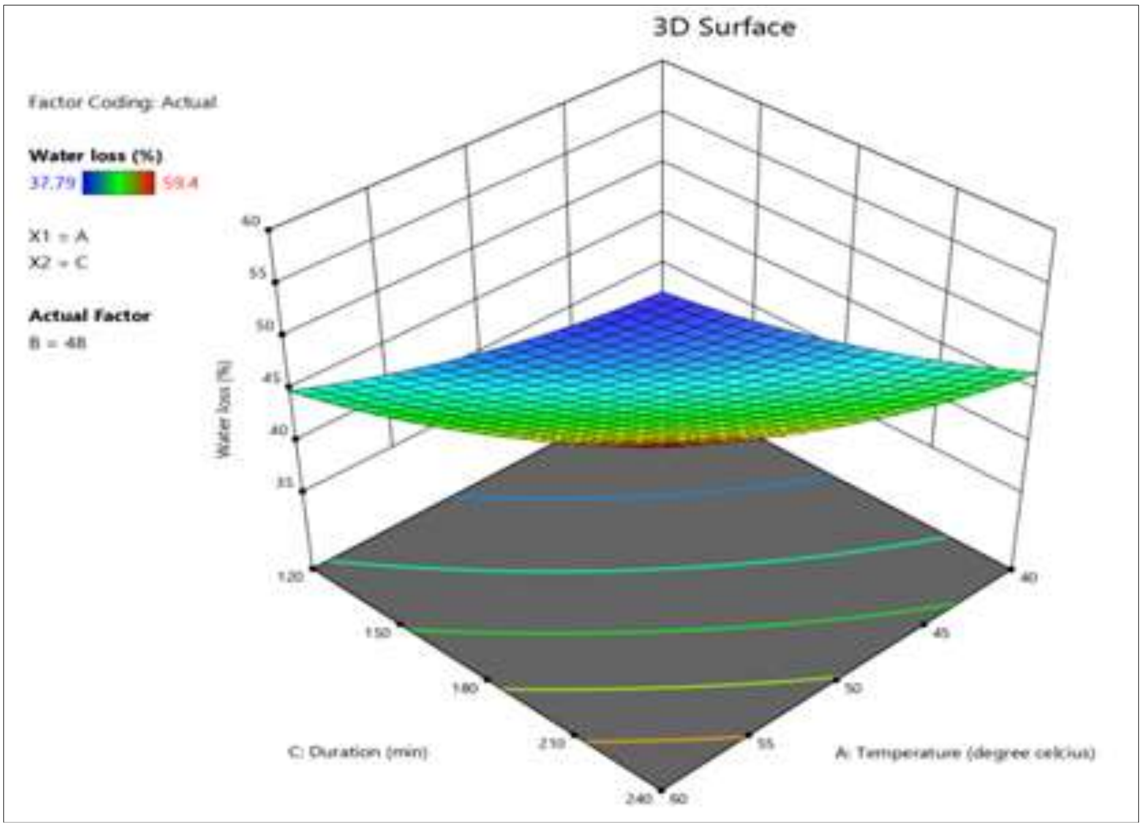


Fig 1: RSM plot shows the temperature, concentration and duration on water loss during osmotic dehydration.

Sugar gain

The observed data for sugar gain under varying processing parameters has been given in table 2. The sugar gain during the osmotic dehydration was found to be dependent on the syrup temperature, concentration and duration of osmosis.

The data for sugar gain were analysed for stepwise regression analysis as shown in Table 4. The quadratic model was fitted with the experimental data and statistical significance for linear and quadratic terms was calculated for sugar gain as shown in Table 4. The R^2 value was calculated by least square technique and found to be 0.9752 showing good fit of model to the data. The model F value of 86.68 implies that the model is significant ($p<0.0001$). The linear terms (C, T and θ) are significant ($p<0.0001$). The lack of fit F value was non-significant, which indicates that the developed model was adequate for predicting the response. Moreover, the predicted R^2 of 0.9912 was in reasonable agreement with adjusted R^2 of 0.9982. This revealed that the non-significant terms have not been included in the model. Therefore, this model could be used to navigate the design space.

High value of coefficient of determination (R^2 = 0.9752) obtained for response variable indicated that the developed model for sugar gain accounted for and adequately explained 2.87% of the total variation. The result of analysis of variance indicated that the linear terms of syrup temperature, syrup concentration and duration of osmosis were highly significant at 1% level. The presence of quadratic terms of concentration of syrup and duration of osmosis indicated curvilinear nature of response surface. The quadratic terms of concentration of syrup and duration of osmosis were also highly significant at 1% level while quadratic term of temperature was non- significant.

Table 4: Anova for sugar gain during osmotic dehydration of radish cubes

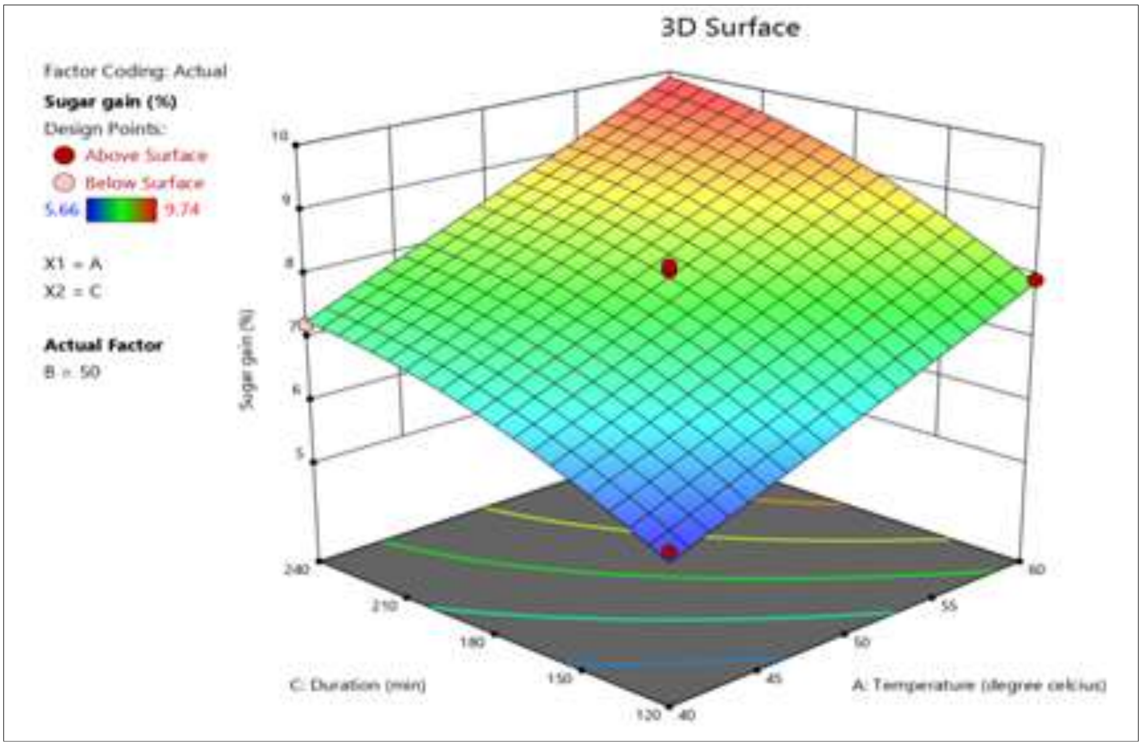
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	21.54	5	4.31	86.68	< 0.0001	significant
A-Temperature	12.63	1	12.63	254.10	< 0.0001	
B-Sugar syrup concentration	0.9522	1	0.9522	19.16	0.0011	
C-Duration	7.28	1	7.28	146.46	< 0.0001	
AB	0.1892	1	0.1892	3.81	0.0769	
C^2	0.4916	1	0.4916	9.89	0.0093	
Residual	0.5466	11	0.0497			
Lack of Fit	0.4724	7	0.0675	3.64	0.1148	not significant
Pure Error	0.0742	4	0.0185			
Cor Total	22.08	16				

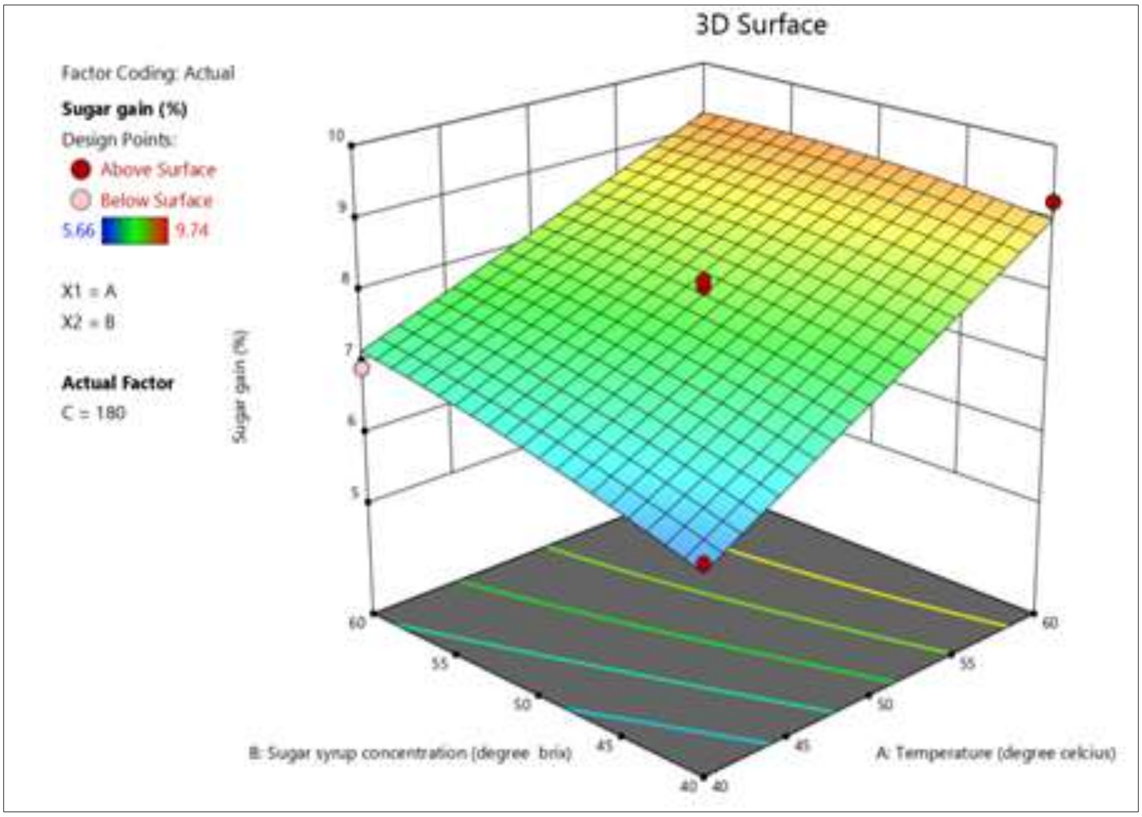
*Significant at 1% level, * Significant at 5% level, NS – Non significant

Std. Dev.	0.2229	R^2	0.9752
Mean	7.76	Adjusted R^2	0.9640
C.V. %	2.87	Predicted R^2	0.9120
		Adeq Precision	33.3771

The comparative effect of each factor on sugar gain could be observed by F values in the ANOVA (Table 4) and also by the magnitudes of the coded variables. The F values indicated that concentration of syrup was the most influencing factor followed by duration of osmosis and temperature of syrup was least effective over sugar gain.

To visualize the combined effect of two variables on the sugar gain, the response surface and 3D surface (Fig 2) were generated for the fitted model as a function of two variables while keeping third variable at its central value. Same as water loss the sugar gain increased rapidly in the early stages of osmosis after which the rate of sugar gain from sugar syrup to radish cubes slowed down with time.





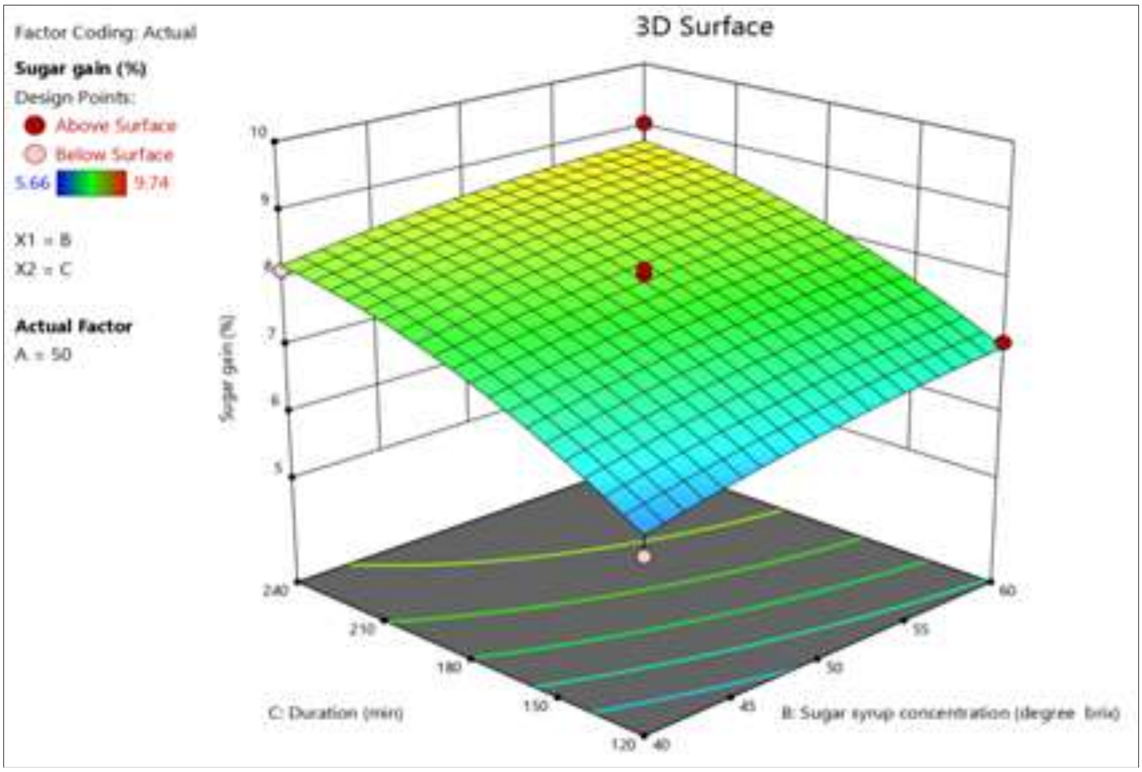


Fig 2: RSM plot shows the effect of temperature, concentration and duration on sugar gain during osmotic dehydration.

The sugar gain was found to increase with temperature. As it was explained for water loss, 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 sugar gain due to fact that lower viscosity decreases the resistance to diffusion of solutes into the sample (Food product) tissue.

Increased concentration of the sugar syrup also led to increase in sugar gain (Fig 2) probably due to an increase of osmotic pressure gradient and consequent loss of functionality of cell plasmatic membrane that allows solute to enter.

Mass reduction: The observed data for mass reduction under varying processing parameters has been given in table 2. The mass reduction during the osmotic dehydration was found to be dependent on the syrup temperature, concentration and duration of osmosis. The initial and final mass of radish cubes, initial and final moisture content of during osmotic dehydration experiments and mass reduction in percent have been presented in Table 5. It can be seen from the table that the initial mass of the radish cubes taken in the study were 30 g. The mass reduction in the range of 32.13 to 49.66% in the experimental range of study. Similarly, initial moisture content of radish was in the range of 87.00 to 91.41% (wb) which was reduced to 57.73 to 76.49% after osmotic dehydration in various experiments.

Table 5: Anova for mass reduction during osmotic dehydration of radish

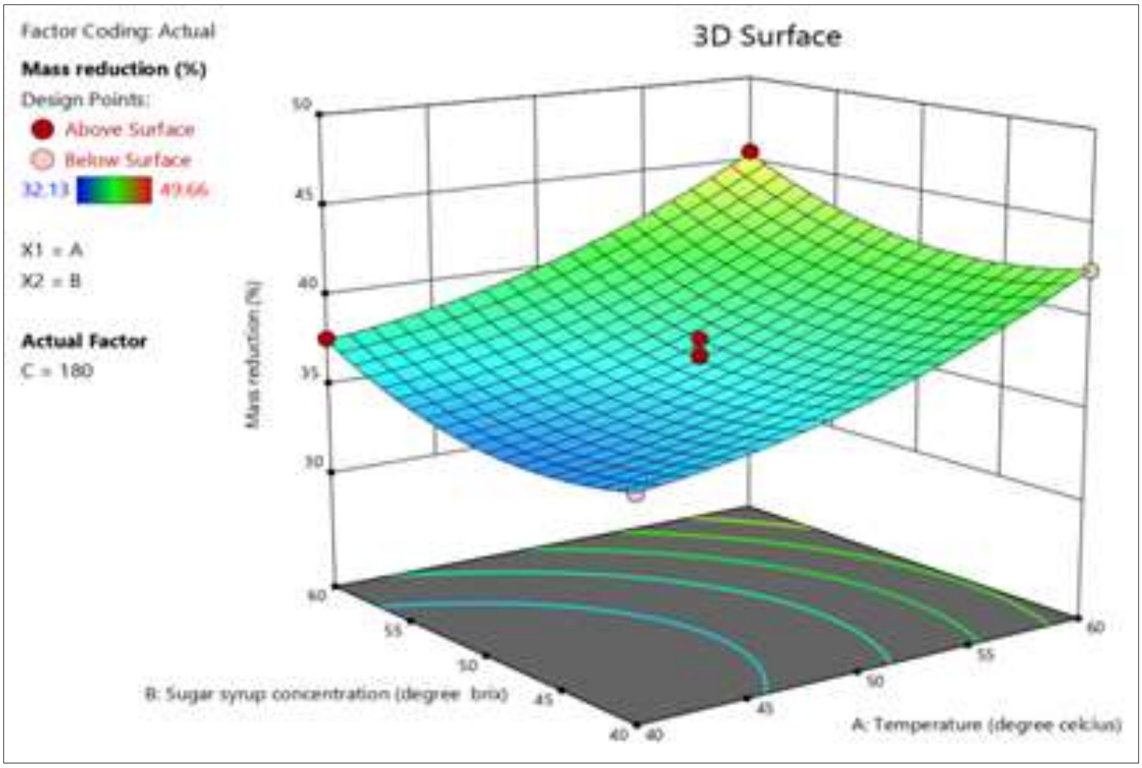
Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	390.99	9	43.44	57.06	< 0.0001	significant
A-Temperature	119.58	1	119.58	157.07	< 0.0001	
B-Sugar syrup concentration	14.50	1	14.50	19.04	0.0033	
C-Duration	217.36	1	217.36	285.50	< 0.0001	
AB	0.0324	1	0.0324	0.0426	0.8424	
AC	4.77	1	4.77	6.27	0.0407	
BC	1.53	1	1.53	2.00	0.1999	
A^2	6.18	1	6.18	8.12	0.0247	
B^2	14.20	1	14.20	18.65	0.0035	
C^2	9.46	1	9.46	12.43	0.0097	
Residual	5.33	7	0.7613			
Lack of Fit	0.7944	3	0.2648	0.2336	0.8690	not significant
Pure Error	4.53	4	1.13			
Cor Total	396.32	16				

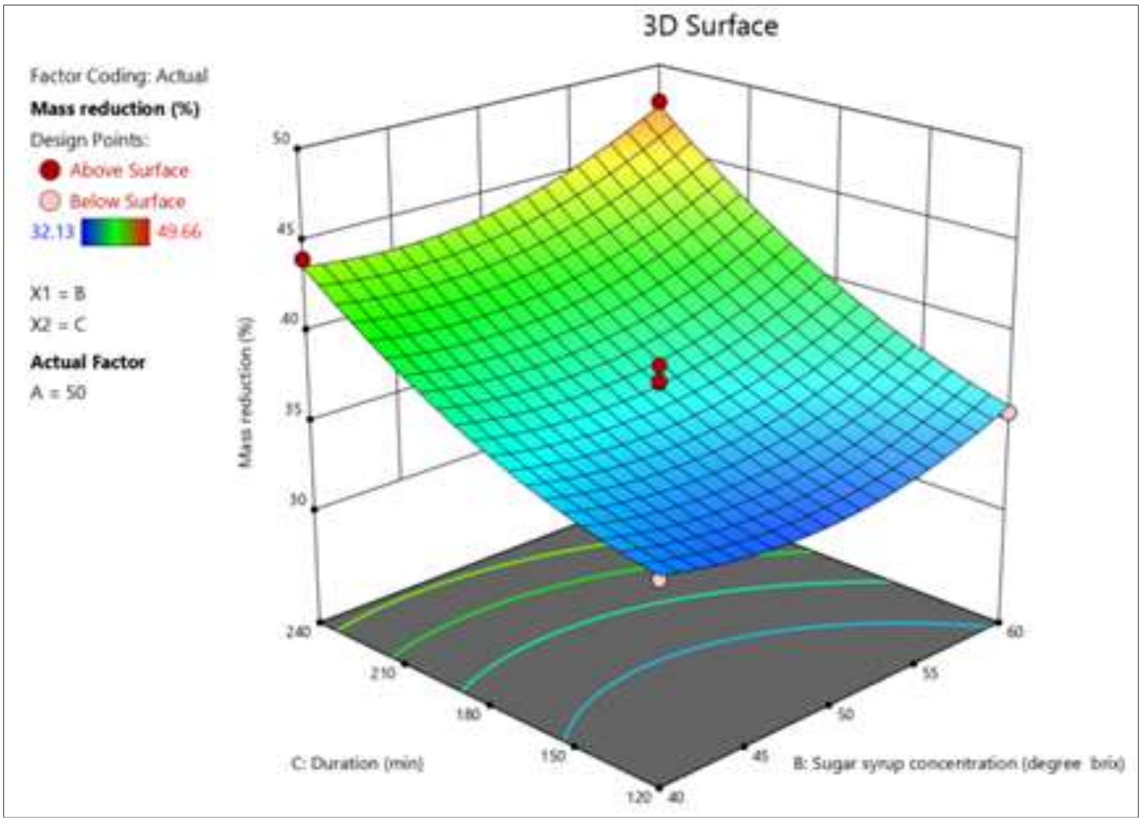
*Significant at 1% level, * Significant at 5% level, NS – Non significant

Std. Dev.	0.8725	R^2	0.9866
Mean	39.23	Adjusted R^2	0.9693
C.V. %	2.22	Predicted R^2	0.9500
		Adeq Precision	27.1328

The quadratic model was fitted to the experimental data and statistical significance for linear, quadratic and interaction terms was calculated for mass reduction as shown in Table 5. The R^2 value was calculated by least square technique and found to be 0.9866 showing good fit of model to the data. The model F value of 57.06 implies that the model is significant ($p<0.0001$). The linear terms (A, B and C) are significant ($p<0.0001$). The lack of fit F value was non-significant which indicated that the developed model was adequate for predicting the response. Moreover, the predicted R^2 of 0.9500 was in reasonable agreement with adjusted R^2 of 0.9693. This revealed that the non-model significant terms have not been included in the model. Therefore, this model could be used to navigate the design space.

High value of coefficient of determination (R^2 = 0.9866) obtained for response variable indicated that the developed model for mass reduction accounted for and adequately explained 98.66% of the total variation. The result of analysis of variance indicated that the linear terms of syrup temperature, syrup concentration and duration of osmosis were highly significant at 1% level (Table 5).





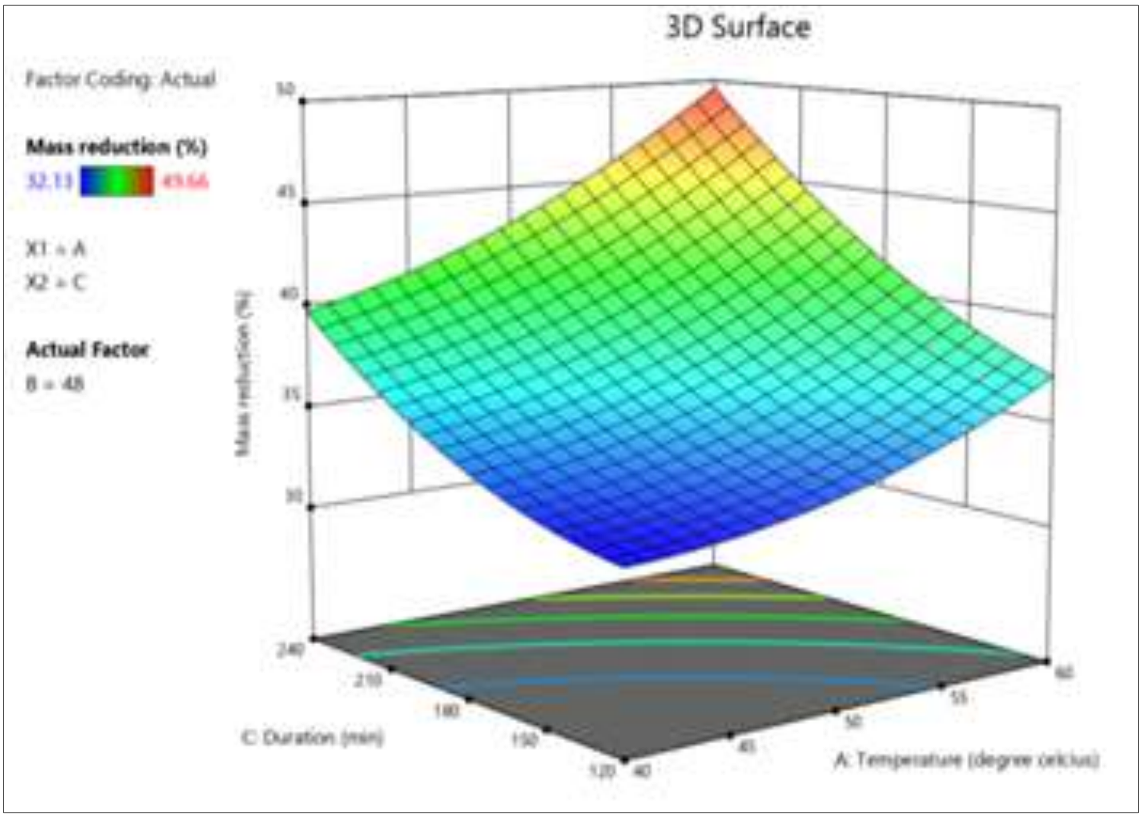


Fig 3: RSM plot shows the effect of temperature, concentration and duration on mass reduction during osmotic dehydration.

The presence of quadratic terms of concentration of syrup and duration of osmosis indicated curvilinear nature of response surface. The comparative effect of each factor on mass reduction was observed by the F values in the ANOVA (Tables 5) and also by the magnitudes of coefficients of the coded variables. The F values indicated that concentration of syrup was the most influencing factor followed by duration of osmosis and temperature of syrup was least effective over mass reduction.

To visualize the combined effect of two variables on the mass reduction, the response surface and 3D surface (Fig 3) were generated for the fitted model as a function of two variables while keeping third variable at its central value. Same as water loss the mass reduction increased rapidly in the early stages of osmosis after which the rate of sugar gain from sugar syrup to radish cubes slowed down with time.

Colour L (Lightness)

The observed data for colour (lightness) under varying processing parameters has been given in table 2. The colour (Lightness) during the osmotic dehydration was found to be dependent on the syrup temperature, concentration and duration of osmosis.

The variation in colour (lightness) by changing syrup temperature, syrup concentration and osmosis duration has been presented in Table 2. The range of colour (lightness) of 54.52 to 84.91 during different treatment conditions.

Table 6: Anova for during colour value (lightness) osmotic dehydration of radish cubes

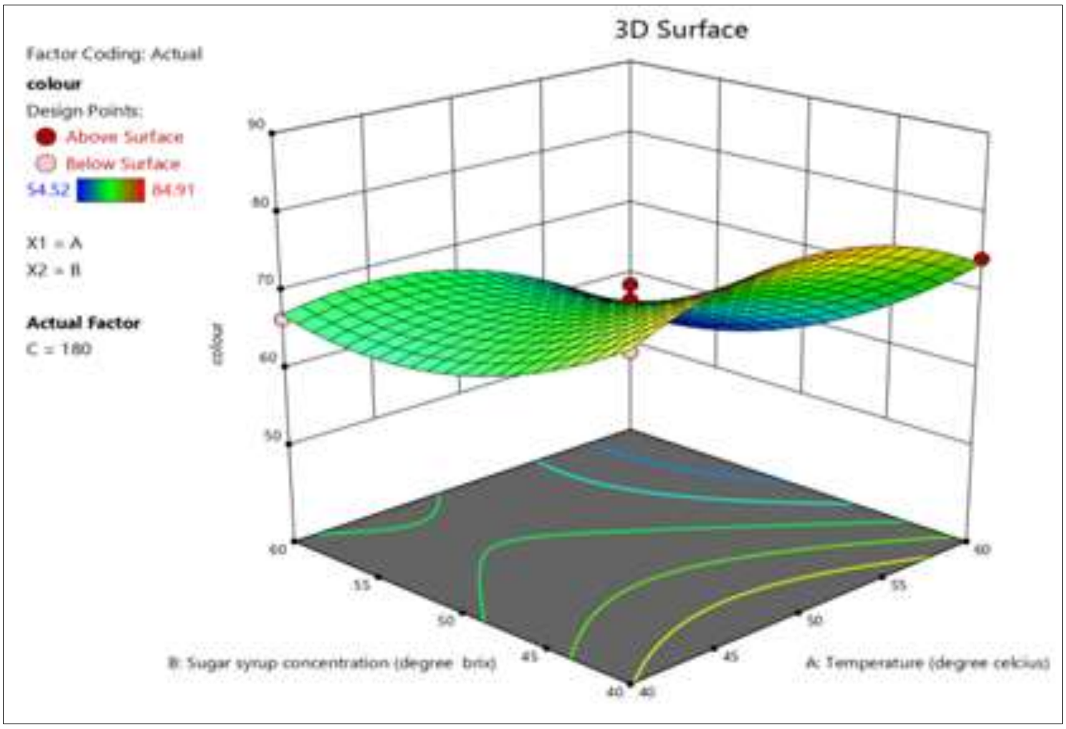
Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	877.28	9	97.48	47.59	< 0.0001	significant
A-Temperature	122.07	1	122.07	59.60	0.0001	
B-Sugar syrup concentration	411.99	1	411.99	201.16	< 0.0001	
C-Duration	47.24	1	47.24	23.07	0.0020	
AB	25.50	1	25.50	12.45	0.0096	
AC	0.1722	1	0.1722	0.0841	0.7802	
BC	2.71	1	2.71	1.32	0.2881	
A^2	150.22	1	150.22	73.35	< 0.0001	
B^2	114.60	1	114.60	55.96	0.0001	
C^2	16.50	1	16.50	8.06	0.0251	
Residual	14.34	7	2.05			
Lack of Fit	3.61	3	1.20	0.4492	0.7316	not significant
Pure Error	10.72	4	2.68			
Model	877.28	9	97.48	47.59	< 0.0001	significant

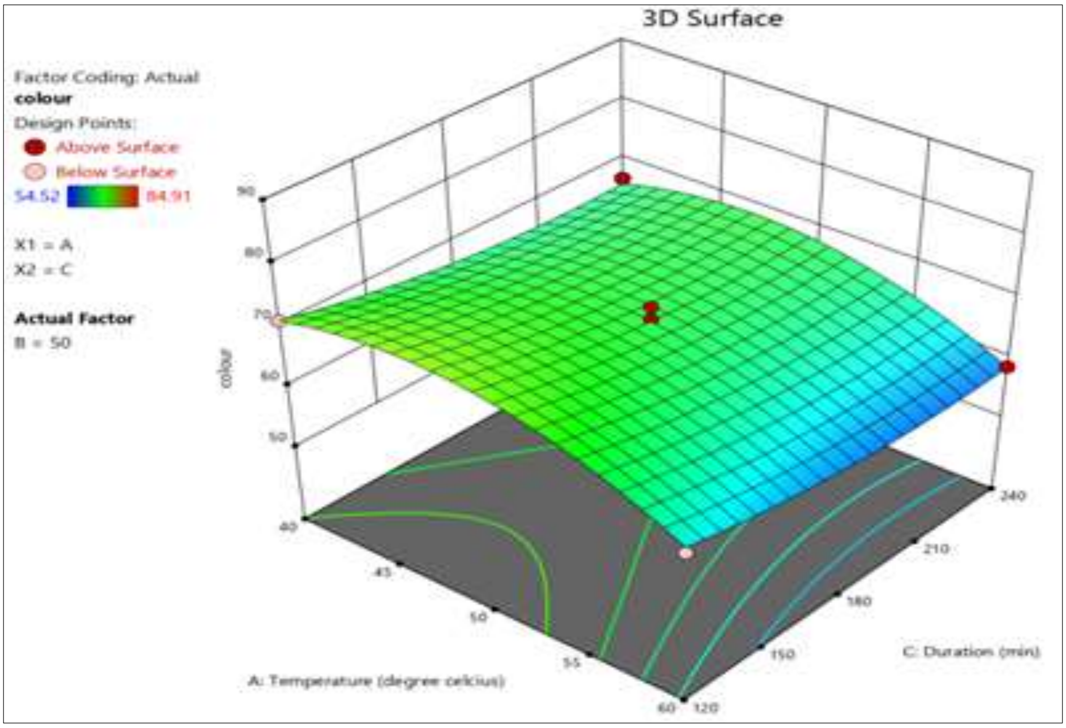
*Significant at 1% level, * Significant at 5% level, NS – Non significant

Std. Dev.	1.43	R^2	0.9839
Mean	69.19	Adjusted R^2	0.9632
C.V. %	2.07	Predicted R^2	0.9164
		Adeq Precision	27.6455

The quadratic model was fitted to the experimental data and statistical significance for linear, quadratic and interaction terms was calculated for colour value (lightness) as shown in Table 6. The R^2 value was calculated by least square technique and found to be 0.9839 showing good fit of model to the data. The model F value of 47.59 implies that the model is significant ($p<0.0001$). The linear terms (A, B and C) are significant ($p<0.0001$). The lack of fit F value was non-significant which indicated that the developed model was adequate for predicting the response. Moreover, the predicted R^2 of 0.9164 was in reasonable agreement with adjusted R^2 of 0.9632. This revealed that the non-model significant terms have not been included in the model. Therefore, this model could be used to navigate the design space.

High value of coefficient of determination (R^2 = 0.9839) obtained for response variable indicated that the developed model for mass reduction accounted for and adequately explained 98.39% of the total variation. The result of analysis of variance of Eqn. indicated that the linear terms of syrup temperature, syrup concentration and duration of osmosis were highly significant at 1% level (Table 6). The presence of quadratic terms of concentration of syrup and duration of osmosis indicated curvilinear nature of response surface.





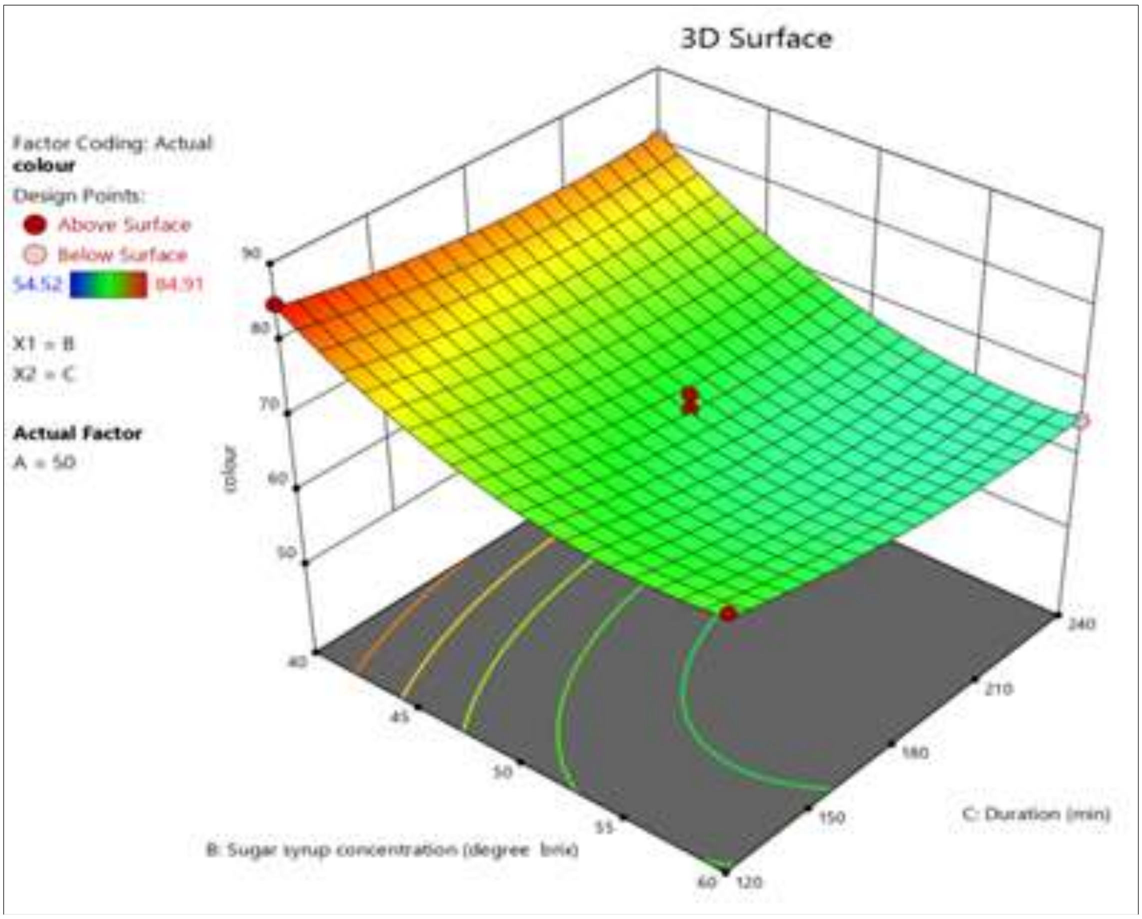


Fig 4: RSM plot shows the effect of temperature, concentration and duration on colour (lightness) during osmotic dehydration.

The comparative effect of each factor on colour (Lightness) was observed by the F values in the ANOVA (Tables 6) and also by the magnitudes of coefficients of the coded variables. The F values indicated that concentration of syrup was the most influencing factor followed by duration of osmosis and temperature of syrup was least effective over colour (Lightness).

To visualize the combined effect of two variables on the mass reduction, the response surface and 3D surface (Fig 4) were generated for the fitted model as a function of two variables while keeping third variable at its central value

The colour (Lightness) was found to decrease with temperature. Increased concentration of the sugar syrup also led to decrease in colour (Lightness) (Fig 4) probably due to an increase of osmotic pressure gradient and consequent loss of functionality of cell plasmatic membrane that allows solute to enter.

Optimization criteria for different process variables and responses for osmotic dehydration of radish cubes.

Parameter	Goal	Lower limit	Upper limit	Importance
Concentration, °B	Minimize	40	60	3
Temperature, °C	Minimize	40	60	3
Duration, min	Minimize	120	240	3
Water loss, %	Maximize	37.79	59.40	3
Colour (lightness)	Maximize	54.52	84.91	3
Sugar gain, %	Target = 8.45	5.66	9.74	3

Table 7: Solution generated by the software for osmotic dehydration of radish cubes.

Concentration, °B	Temperature, °C	Duration, min	Water loss, %	Sugar gain, %	Colour (lightness)
40	52.47	238.578	53.34	8.45	80.66

The predicted values and actual reported values for any response differed non-significantly ($p<0.05$)

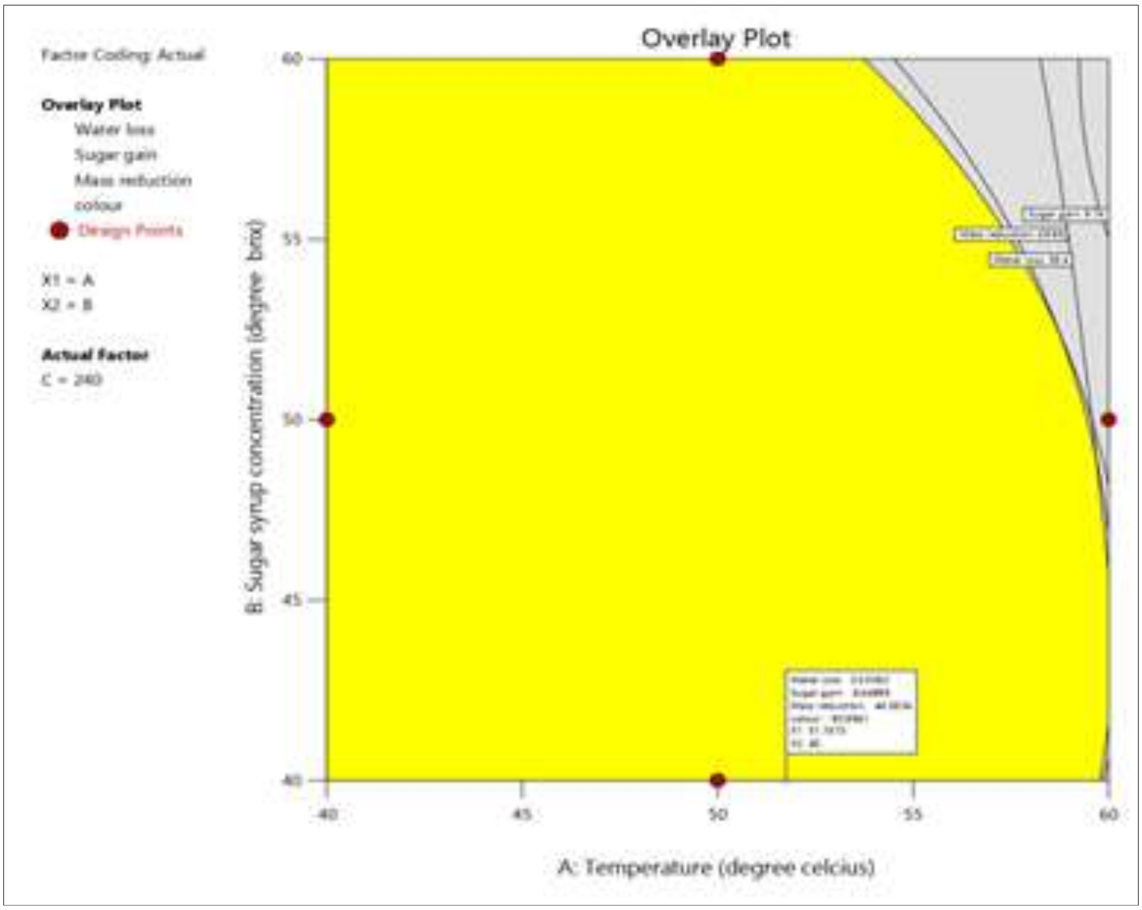


Fig 5: Superimposed contours for water loss (%), sugar gain (%), mass reduction (%) and colour (lightness) for osmotic dehydration of radish cubes.

A graphical multi response optimization technique was adapted to determine the workable optimum conditions for the osmotic dehydration of radish cubes. The 3D surface plots for all responses were superimposed and regions that best satisfy all the constraints were selected as optimum conditions.

Conclusions

Using graphical optimization technique, the superimposed contours of all responses for concentration of syrup (C), temperature of syrup (T) and duration of osmosis (θ) and their intersection zone for maximum water loss and targeted sugar gain, maximum colour (L) indicated the optimum values of process variables. The superimpose graph recorded the optimum process parameters i.e., syrup temperature 52.47 °C, sugar concentration 40°B and duration or time 238.57 min for determined the various responses i.e. 53.34% water loss and 8.45% sugar gain and 80.66 colour (L). Results of validation tests were highly acceptable since the coefficient of Regression Coefficient (R greater than 0.98) and coefficient of variation (CV <5%) of the responses.

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