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Original Research Paper

Optimization of osmotic dehydration in dragon fruit (*Hylocereus polyrhizus*) slices using response surface methodology

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ABSTRACT

Dragon fruit (*Hylocereus polyrhizus*) is emerging as a super crop because of its several health and therapeutic benefits and ease of cultivation even in degraded land. Using response surface approach, the process parameters for osmotic dehydration of dragon fruit slices included process temperature, syrup concentration and process time. Slices of size 20 x 20 x 5 mm were dipped into sugar syrup with a syrup to dragon fruit slice ratio of 4:1 (w/w). After osmotic dehydration, the initial moisture content of dragon fruit samples was reduced to 27.5-68.49% (wb), demonstrating water loss, solid gain, and mass reduction in the range of 18.01-65.9%, 6.3-17.9% and 9.31-50.6%, respectively. After statistical analysis of the data on water loss, solid gain, and weight reduction, it was shown that regression equations of second order provided the greatest match for all the experimental data. With a syrup to fruit ratio of 4:1 and a syrup concentration of 65.3° Brix at a syrup temperature of 56.5°C, a maximum water loss of 58.2% and a minimum solid gain of 7.7% were expected to occur in 240 minutes of osmotic dehydration.

Keywords : Dragon fruit, optimization, osmotic dehydration, solid gain, water loss

INTRODUCTION

Dragon fruit have numerous nutritional advantages, as well as its ease of growing even on degraded land. It contains essential minerals and nutrients like potassium, iron, sodium, calcium and fiber, and good source of antioxidants. It is able to lower cholesterol concentration to balance blood sugar and to prevent colon cancer to strengthen kidney functioning and bone strength. It has the ability to promote the growth of probiotics in the intestinal tract (Le et al., 2021). The hot air-dried fruits in traditional trays, cabinets or vacuum dryers are not widely accepted due to the low product quality. The issues with products made from air-dried fruits include woody texture, slow or insufficient rehydration of the product, loss of juiciness, and significant shrinkage brought on by the collapsing of cells as a result of significant water loss (Dalla Rosa & Giroux, 2001). It also results in unfavourable colour, flavour, and nutritional quality changes (Jain & Verma, 2003).

One potential preservation method for creating high-quality products is osmotic dehydration (Kar & Gupta, 2001; Rastogi et al., 2002; Sodhi et al., 2006). Numerous variables affect water removal in case of osmotic dehydration (Dalla Rosa & Giroux, 2001) and is used to enhance the fruit's nutritive, sensory and functional qualities (Sujayasree et al., 2022).

MATERIALS AND METHODS

The dragon fruits of var. Taiwan pink were blanched in hot water to ensure that all impurities on the fruit's surface were eliminated. Peeled out fruit was cut into slices of size 20 x 20 x 5 mm and utilised for this study.

Osmotic dehydration of dragon fruit slices

The moisture content of dragon fruit slices was determined as per the method 934.06 (Cunniff & Washington, 1977). Sugar syrup to fruit ratio of 4:1 was used to osmotically dehydrate the dragon fruit slices. The beakers containing the sugar syrup and dragon fruit slices were positioned inside the water bath at a constant temperature. To keep a consistent temperature, the syrup in the beakers was manually stirred at regular intervals. At the predetermined time, one beaker was taken out of the water bath and the samples were quickly washed with running water before being placed on tissue paper to absorb any remaining surface moisture. The moisture content of the samples at that condition were determined. For each processing parameter, such as syrup concentration (40, 50, 60, 70° Brix), temperature (40, 50, 60, 70°C) and osmotic duration (30, 60, 90, 120, 150, 180, 210, 240 min), levels were chosen based on recommendations made by prior researchers (Dalla Rosa & Giroux, 2001; Torreggiani & Bertolo, 2001; Ozen et al., 2002; Jain et al., 2011).

Determination of water loss, solid gain and weight reduction

The water loss (WL), solid gain (SG) and weight reduction (WR) of fruit slices were estimated as per the procedure given by Kaleemullah et al. (2002).

$$WL = \frac{M_o X_o - M_\theta X_\theta}{M_o} \times 100 \quad \text{......... (1)}$$

where,

WL = water loss, %

M_o= mass of dragon fruit slices at time zero, g

M_θ = mass of dragon fruit slices at time, $_\theta$, g

X_o= water content as a fraction of mass of dragon fruit slices at time zero

X_θ= water content as a fraction of mass of dragon fruit slices at time θ

The dry matter gain is related to SG and hence, the SG was the net gain in total solids by dragon fruit slices on initial mass basis.

$$SG = \frac{M_\theta(1-X_\theta) - M_o(1-X_o)}{M_o} \times 100 \quad \text{......... (2)}$$

where,

SG = solid gain, %

Weight reduction is defined as the weight lost from the dragon fruit slices during osmotic dehydration process and was calculated on the basis of initial

Table 1 : Central composite design (CCD) experimental treatment combinations obtained by Design Expert for three independent process parameters

Run	Solution concentration (°Brix)	Solution temperature (°C)	Immersion time (min)	Remarks
04	40	40	030	Non centric points
02	70	40	030	
05	40	40	240	
19	70	40	240	
09	40	70	30	
17	70	70	30	
14	40	70	240	
01	70	70	240	
10	40	55	135	
11	70	55	135	
06	55	55	30	
15	55	55	240	
16	55	40	135	
13	55	70	135	
08	55	55	135	Centric points
12	55	55	135	
13	55	55	135	
18	55	55	135	
07	55	55	135	
03	55	55	135	

weight. Weight reduction is the difference between the water loss and solid gain.

$$WR = WL - SG \quad \text{.......... (3)}$$

where,

WR = weight reduction, %

WL = water loss, %

SG = solid gain, %

The osmotic dehydration experiments for dragon fruit slices with different osmotic solution concentrations, osmotic solution temperatures and dehydration durations were planned by using the statistical analysis tool Design Expert (Stat Ease, MN 55413, USA, Version 13.0). Osmotic solution concentration, temperature and dehydration duration were chosen as the three independent process factors for this. With the help of fitting models offered by Design Expert software, ANOVA tables were generated, and the coefficient of determination (R^2) and coefficient of variance (CV) were also calculated. In cases where objectives like minimise, maximise, within range, target set to an exact value (factors only), and none (responses only) were available, numerical optimization was employed to improve the responses. Maximizing water loss, reducing solid gain, and maximising weight reduction were the criteria used for optimization. Additionally, the central composite design (CCD) response surface model was chosen with the intention of improving the process parameters. Osmotic dehydration process variables included osmotic solution concentration, temperature and immersion time, which ranged from 40 to 70° Brix, 40 to 70°C and 30 to 240 min, respectively. The response metrics chosen were water loss, solid gain and weight reduction. Twenty randomised treatment combinations were offered by CCD of Design Expert with 14 non-centre points and 6 centre points (Table 1).

Table 2 : Average experimental value of water loss, solid gain and weight reduction at 20 different experimental conditions

Run	Solution concentration (°Brix)	Solution temperature (°C)	Immersion time (min)	Water loss (%)	Solid gains (%)	Weight reduction (%)
01	40	40	30	18.01	8.7	9.31
02	70	40	30	19.7	9.3	10.4
03	40	40	240	25.2	11.5	13.7
04	70	40	240	42.2	7.4	34.8
05	40	70	030	30.4	11.6	18.8
06	70	70	030	48.0	12.3	35.7
07	40	70	240	40.3	16.3	24.0
08	70	70	240	65.9	17.9	48.0
09	55	40	135	27.2	9.0	18.2
10	70	55	135	43.9	6.3	37.6
11	55	55	030	27.7	7.00	20.7
12	55	55	240	59.6	9.0	50.6
13	55	40	135	29.3	7.6	21.7
14	55	70	135	58.9	12.8	46.1
15	55	55	135	44.1	6.4	37.7
16	55	55	135	46.6	6.7	39.9
17	55	55	135	44.1	6.5	37.6
18	55	55	135	44.2	6.4	37.8
19	55	55	135	44.2	6.4	37.8
20	55	55	135	44.3	6.3	38.0

Optimization of independent parameters for osmotic dehydration process

The concentration of the osmotic solution, temperature, and immersion duration were three distinct process parameters that were optimised using the numerical optimization approach of RSM in design expert software. For optimising and choosing the optimal treatment combination, the experimental data of water loss, solid gain, and weight reduction of dragon fruit slices during osmotic dehydration at the various treatment combinations were used. The experimental data were fitted using a second order polynomial equation, which describes the impact of the test variables (A, B, C) as well as their combined and interaction effects on the predicted response (Y).

$$Y_i = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 + \beta_{12} AB + \beta_{23} BC + \beta_{13} AC + E \quad ..(4)$$

where,

Y_i (i = 1-3) = predicted responses for water loss, solid gain and weight reduction

β_0 = Estimated coefficient at center of the design

$\beta_1, \beta_2, \beta_3$ = linear coefficients

$\beta_{11}, \beta_{22}, \beta_{33}$ = quadratic coefficients

$\beta_{12}, \beta_{23}, \beta_{13}$ = interaction coefficients

A = Solution temperature, °C

B = solution concentration, °Brix

C = immersion time, min

E = random error

RESULTS AND DISCUSSION

Mass transfer parameters of osmotically dehydrated dragon fruit slices

The mass transfer parameters such as water loss, solid gain and weight reduction for osmotically dehydrated dragon fruit slices at different experimental conditions are presented in Table 2. The analysis of variance (ANOVA) was carried out to evaluate the impact of process factors on the experimental values of response variables and the quadratic model was found significant ($p<0.05$).

The three response variables also produced second order polynomial equations. The terms that had a distinct impact on the response variables are also supplied. By using the programme to display the combined influence of two independent process factors on a specific dependent response variable, the 3-D response surface plots for dependent parameters were created. The numerical optimization method was used to carry out the optimization. All the parameters were given equal weight, and the optimum value was discovered. The regression coefficients for the three response variables were obtained by using Design Expert (Table 3).

Water loss response during osmotic dehydration of dragon fruit slices

When dragon fruit slices were exposed to osmotic solutions with concentrations of 40-70° Brix, solution temperatures of 40-70°C and immersion periods of

Table 3 : Regression coefficient values of response variables

Variables	Water loss	Solid gain	Weight reduction
Intercept	44.28	6.37	37.91
A	11.12****	2.50****	8.62****
B	7.65****	-0.25****	7.90****
C	8.94***	0.9900***	7.95***
AB	3.06**	0.7250**	2.34**
AC	-0.2375**	1.18**	-1.41**
BC	2.91**	-0.4750**	3.39**
A^2	0.7773**	4.66**	-5.44**
B^2	-7.23***	0.709***	-7.94***
C^2	-0.1733**	0.1091**	-0.2864**
R^2	0.9410	0.9485	0.9108

A: osmotic solution concentration, B: solution temperature, C: immersion time.

****p < 0.05, 0.05 ≤ ***p < 0.1, **p ≥ 0.1

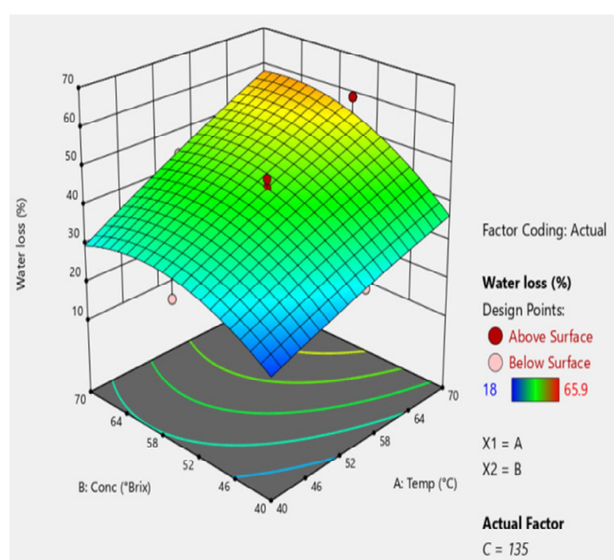
30–240 min, water loss (WL) values ranged from 18.01% to 65.9%. At a solute concentration of 70 °Brix, temperature of 70°C and an immersion time of 240 min, a higher water loss value of 65.9% was attained. At a sugar solution concentration of 40° Brix, temperature of 40°C, and an immersion time of 30 min, a lower water loss value of 18.01% was obtained. The coefficient of determination (R^2) value for the water loss equation was 0.9410. The quadratic model's F-value for the water loss parameter was 17.72, and this result shows that the model's significance for the water loss response was high. The model terms are considered significant ($p<0.05$) if the independent parameter p-value was less than 0.05. For the water loss parameter of slices of dragon fruit, the following model terms are significant in the current study ($p<0.05$): A, B, C, AB, A^2, and B^2. P-values higher than 0.10 denote the absence of significance for the model terms. F-value is 187.64 and P-value is 0.0001 for the water loss parameter's lack of fit value. It suggests that the lack of fit is important for the water loss parameter of slices of dragon fruit. In terms of the actual values of the variables, a regression equation was created to account for water loss.

$$\text{Water loss (\%)} = -90.16209 + (0.393079 \times A) + (0.393079 \times B) + (-0.003928 \times C) + (0.013611 \times AB) + (-0.000151 \times BC) + (0.001849 \times AC) (-0.003455 \times A^2) + (-0.032121 \times B^2) + (-0.000016 \times C^2) \;\ldots.\; (5)$$

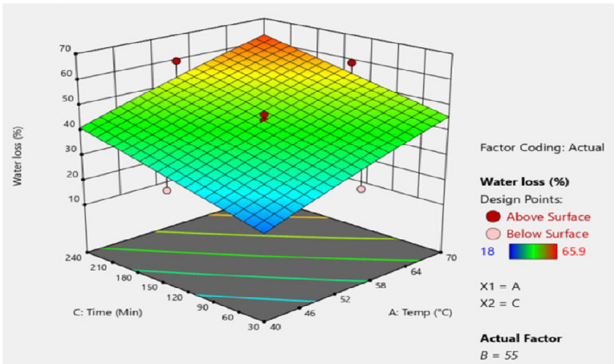
The response surface plots for water loss during osmotic dehydration are depicted in Fig. 1. As solute concentration, immersion time, and temperature increased, water loss also increased. During osmotic dehydration, the water loss value of dragon fruit slices increased as the solute concentration and solution temperature increased. This may be due to the increase of osmotic pressure differential between the fruit and the interface of the osmotic solution and decrease in the sugar solution's viscosity. Increase in water loss with an increase in solute concentration and solution temperature has been reported in osmotic dehydration of papaya (Kaleemullah et al., 2002), pineapple slices (Rastogi & Raghavarao, 2004) and beetroot slices (Kaur & Singh, 2013). All the three process variables (process temperature, syrup concentration and process time) had a substantial favourable impact ($p<0.05$) on the water loss of dragon fruit slices during osmotic dehydration at the linear level. Dragon fruit slices water loss was significantly positively influenced by solution concentration and solution temperature at the interaction level ($p < 0.05$), but not by solution temperature and immersion time. All the three independent process parameters had a negative impact on water loss at the quadratic level, with temperature and concentration having the most notable effects ($p < 0.05$).

Solid gain response during osmotic dehydration of dragon fruit slices

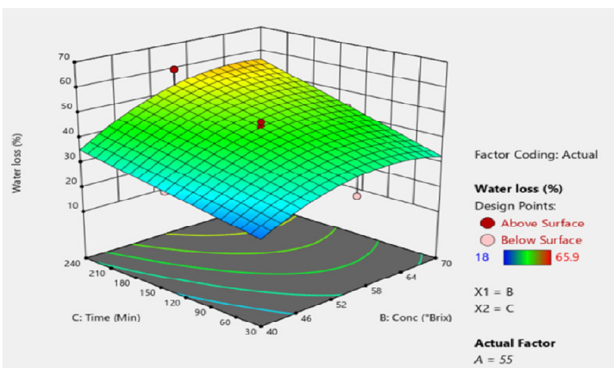
The solid gain (SG) values of dragon fruit slices for osmotic solutions with concentrations of 40-70° Brix, solution temperatures of 40-70°C, and immersion periods of 30-240 min ranged from 6.3% to 17.9%. A sugar solution with a concentration of 70° Brix, a temperature of 70°C, and an immersion duration of 240 minutes produced a higher solid gain value of 17.9%. At a concentration of 55 °Brix, a temperature of 55°C, and an immersion time of 135 minutes, a lower solid gain value of 6.3% was attained. The coefficient of determination (R^2) value for the solid gain equation was 0.9485. The solid gain parameter's F-value from the quadratic model was 20.47, which shows that the solid gain response was significant for the quadratic model ($p< 0.05$). The model terms are significant if the p-value of the independent terms was less than 0.05. In this instance, the solid gain parameter of dragon fruit slices has significant ($p<0.05$) model terms A, B, C, A^2, and B^2. P-values higher than 0.10 denote the absence of significance for the model terms. F-value is 12.09 and p-value is 0.0001 for the solid gain parameter's lack of fit value.



(a) Water loss (%) of dragon fruit slices as a function of solution concentration and temperature



(b) Water loss (%) of dragon fruit slices as a function of solution temperature and immersion time



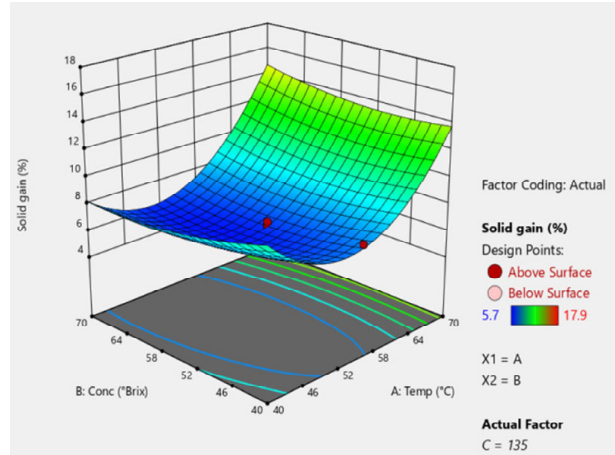
(c) Water loss (%) of dragon fruit slices as a function of solution concentration and immersion time

Fig. 1(a-c) : Response surface plots showing effect of process parameters on water loss of dragon fruit slices during osmotic dehydration

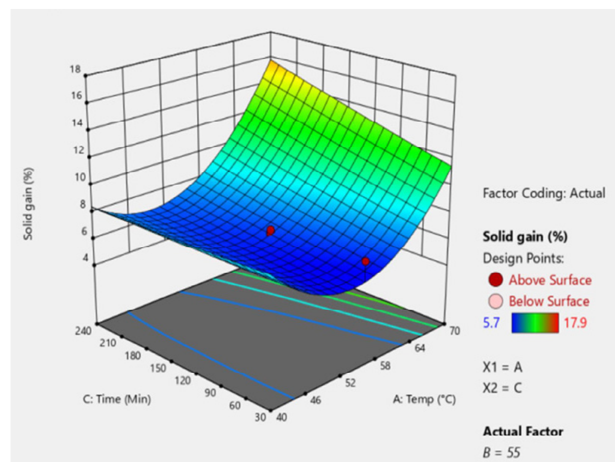
It suggests that the solid gain parameter of dragon fruit slices is significant for the lack of fit. One can predict the outcome of the equation using actual values for the variables as follows:

Solid gain (%) = 82.24328+ (-2.38905× A) + (-0.499841× B) + (-0.499841× C) + (0.003222 × AB) + (0.000746 × BC) + (-0.000302 × AC) +(-0.000302 × A^2) + (0.003152 × B^2) + (9.89487E-0.6×C^2) ….. (6)

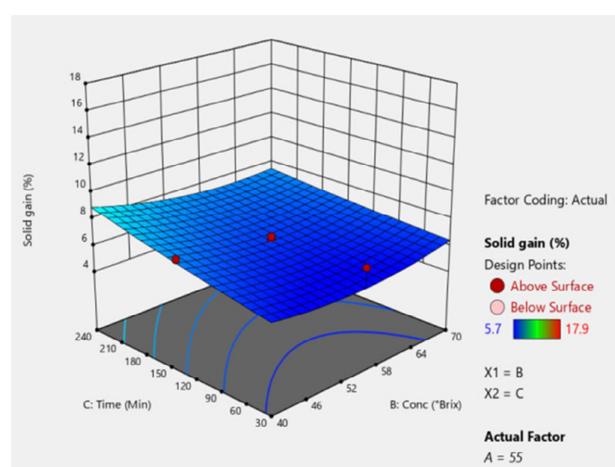
The solid gain increased with an increase in solution concentration, solution temperature and immersion time (Fig. 2). In comparison to solute concentration and immersion period, solution temperature had the greatest impact on the solid gain of dragon fruit slices as documented in carrot slices (Uddin et al., 2004), strawberry slices (Rizzolo et al., 2007) and papaya slices (Jain et al., 2011). All the three independent process parameters (process temperature, syrup concentration and process time) significantly improved the solid gain of dragon fruit slices during osmotic



(a) Solid gain (%) of dragon fruit slices as a function of solution concentration and temperature



(b) Solid gain (%) of dragon fruit slices as a function of solution temperature and immersion time



(c) Solid gain (%) of dragon fruit slices as a function of solution concentration and immersion time

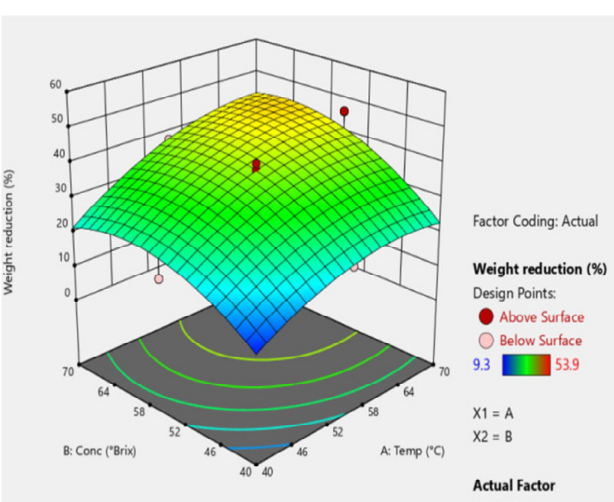
Fig. 2(a-c) : Response surface plots showing effect of process parameters on solid gain of dragon fruit slices during osmotic dehydration

Weight reduction response during osmotic dehydration of dragon fruit slices

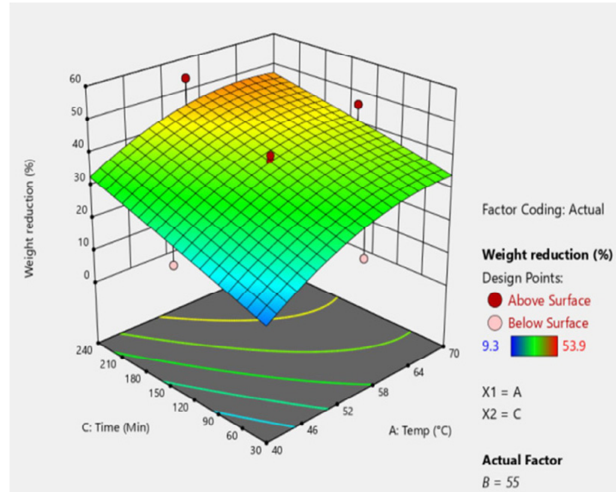
The weight reduction (WR) values of dragon fruit slices for osmotic solutions with concentrations of 40-70° Brix, solution temperatures of 40-70°C, and immersion periods of 30-240 min ranged from 9.31% to 50.60%. At a solution concentration of 70° Brix, solution temperature of 70°C, and immersion period of 240 min, a greater weight loss of 53.9% was obtained. At a solution concentration of 40 °Brix, solution temperature of 40°C and immersion period of 30 min, a lower weight loss of 9.3% was recorded. The coefficient of determination (R^2) value for the weight reduction equation was 0.91. The quadratic model (F-value 11.34) is significant if the $p < 0.05$. P-values higher than 0.10 denote the absence of significance for the model terms. F-value is 27.9 and p-value is 0.0001 for the lack of fit. Making predictions about the response for certain levels of each variable may be done using the equation in terms of real values of the variables as follows:

$$\text{Weight reduction (\%)} = -172.40538 + (2.78213\times A) + (3.54492\times B) + (0.013759\times C) + (0.013759\times AB) + (-0.000897\times BC) + (0.002151\times AC) + (-0.024162\times A2) + (-0.03527 + (0.000026\times C2) \quad \ldots\ldots(7)$$

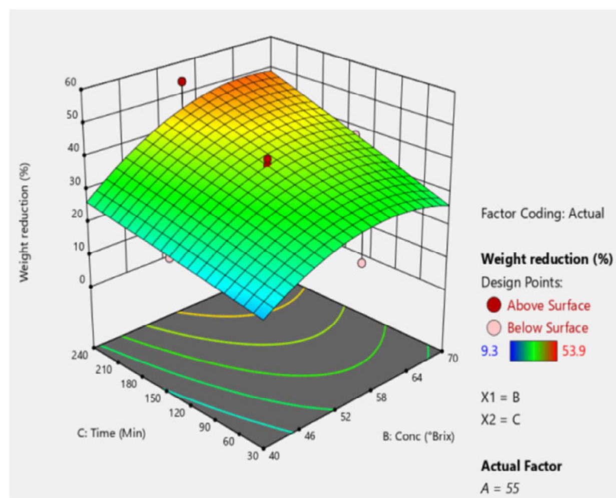
As the solute concentration, solution temperature, and immersion time rose, so did the weight loss of the dragon fruit slices during osmotic dehydration.



(a) Weight reduction (%) of dragon fruit slices as a function of solution concentration and temperature



(b) Weight reduction (%) of dragon fruit slices as a function of solution temperature and immersion time



(c) Weight reduction (%) of dragon fruit slices as a function of solution concentration and immersion time

Fig. 3 (a-c) : Response surface plots showing effect of process parameters on weight of dragon fruit slices during osmotic dehydration

The effect of solution concentration on dragon fruit slice pronounced more weight reduction than the solution temperature and immersion duration ($p< 0.05$) (Fig. 3). All the three process variables had a negative influence on weight reduction at the quadratic level, while, temperature had a statistically significant positive effect ($p< 0.05$) on weight reduction of the dragon fruit slices. Similar observation was quoted by Namrata et al. (2022) in muskmelon cubes. Shrivastava & Gowda (2016) also observed osmotic dehydration of the papaya fruits product with 60 °Brix syrup concentration regarding quality and stability.

CONCLUSION

The effects of sugar syrup concentration, syrup temperature and osmotic time on the osmotic dehydration of dragon fruit slices were investigated. The moisture content of dragon fruit samples was decreased to 27.5-68.49% (wb) after osmotic dehydration, experiments revealing water loss, solid gain, and weight reduction in the ranges of 18.01-65.9%, 6.3-17.9%, and 9.31-50.6%, respectively. It was revealed that the regression equations of second order offered the best fit for all of the experimental data on water loss, solid gain, and weight reduction. A maximum water loss of 58.2% and a minimum solid gain of 7.7% were projected with a syrup to fruit ratio of 4:1 and a syrup concentration of 65.3° Brix at a syrup temperature of 56.5°C in 240 minutes of osmotic dehydration.

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