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Optimization of osmotic dewatering process parameters of jackfruit bulb slices

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Abstract
Response surface methodology (RSM) was used to determine optimum processing parameters i.e., osmotic solution concentration (40-60 °B), solution temperature (40-60 °C) and immersion time (60-180 min) during osmotic dehydration of jackfruit bulb slices by maximizing water loss (WL) and minimizing solid gain (SG) at fruit to solution ratio of 1:4. The water loss and solid gain ranged from 12-35% and 1-14% respectively. The optimized process parameters were osmotic solution concentration of 60 °B, solution temperature of 57 °C and immersion time of 160 min at a maximum water loss of 33.1% and minimum solid gain of 10.2%.

Keywords: Jackfruit bulb slices, central composite rotatable design (CCRD), osmotic dewatering, optimization, response surface methodology (RSM)

Introduction
Jackfruit (*Artocarpus heterophyllus* L.), species of the mulberry family (Moraceae), were majorly produced by Australia, Bangladesh, Brazil, China, India, Indonesia, Malaysia, Myanmar, Philippines, Surinam, Sri Lanka and US. The area and production of jackfruit in India is 1, 87, 000 ha and 18,57,000 MT for the year 2018-2019 (Indiastat, 2019) [6]. It was reported in India that nearly three-fourths of total jackfruit produced gets spoiled because of improper preservation and storage facilities.

Osmotic dehydration is the partial water removal process from biological materials by immersion in concentrated sugar or salt solutions. Major advantages of any biological materials are reduced weight, reduced discolouration and increased acceptability. Osmotic dehydrated products consumption has drawn attention of majority of the food lovers. So, this osmotic dehydration technique has drawn attention of majority of the researchers, food technocrats to explore on wide variety of perishable fruits and vegetables available to increase their shelf life for off-season consumption preferably.

Jackfruit has anti-cancerial properties and indeed increases immunity, endorses in healthy digestion, eye and skin, boosts energy, reduces high blood pressure, controls asthma, strengthens the bone, avoids anaemia and keeps a healthy thyroid. The demand for processed fruits is continuously increasing both as finished products and as ingredients in confectionary and bakery products. Ripe jackfruits are used to make ice cream, drinks, jam, halwa and jelly (APAARI 2012) [3]. Dried pulps are consumed during offseason.

A study was investigated to see the effects of process parameters i.e., osmotic solution concentration, solution temperature and immersion time on mass transfer parameters and quality attributes. A good combination of process parameters results in greater mass transfer parameters. Thus, it is very important to determine optimal conditions to develop osmotically dehydrated product of superior quality.

Materials and Methods
Raw material
Matured jackfruits of firm variety were obtained from local market. Jackfruits were washed in running water to exclude dirt or dust adhered to it. The jackfruits were cut manually using a SS knife and the bulbs were separated manually without the application of any edible oil. The seeds were parted from the bulb manually by vertical slitting using a knife. The bulbs were cut into uniform square shape (2×2 cm) slices with average thickness of 4.5 mm.

Physico-chemical analysis
Moisture content of fresh slice was determined by AOAC (2005) [2]. Total soluble solids (TSS) were measured by hand refractometer (Atago, Tokyo) by grinding the slices in mortar with pestle. The pH and titratable acidity of fresh fruit were determined by the methods given by Ranganna (1986). Sampling was done in triplicate, mean values were noted.

Experimental design

Osmotic solution concentration of 40-60 °B, solution temperature of 40-60 °C and immersion temperature of 60-180 min were used as input process parameters for the experimental design. CCRD was used to design the experiments using Design-Expert trail version 11 (Statease Inc., USA). The data resulted in five osmotic solution concentrations of 33, 40, 50, 60, 67 °B, five solution temperatures of 33, 40, 50, 60, 67 °C and five immersion times of 19, 60, 120, 180 and 221 min respectively. Design gave 20 experiments (Roopa 2012) [9] consisting of coded and real values (Table 1).

Preparation of osmotic solutions

Commercial cane sugar was used as solute in the osmotic solution. Five osmotic solutions of concentrations 33 °B, 40 °B, 50 °B, 60 °B and 67 °B were prepared. Preservatives like citric acid (0.3% w/v, food grade) and potassium metabisulfite (1% w/v, food grade) were added to the osmotic solution. Experiments were conducted at fruit to solution ratio of 1:4. The concentrations of osmotic solutions were tested by hand refractometer.

Osmotic dewatering process

Twenty five grams of jackfruit bulb slices were immersed in SS containers containing different osmotic sugar concentration solutions. The containers were kept in thermostat-controlled oven preset at required temperature. The movements of water and sugar were analyzed by inspecting the samples of jackfruit bulb slices soaked at designated times: 19 min, 60 min, 120 min, 180 min and 221 min. After osmotic dehydration process, the jackfruit slices were taken out of the solution, rubbed gently with muslin cloth to remove the adhered solute on their surfaces and were weighed immediately. The slices were weighed and moisture content was determined by using vacuum oven (AOAC 2005) [2].

Mass transfer parameters

The water loss and solid gain were calculated using the formulae given by Kaleemullah (2002) [7].

$$WL = \frac{\text{Initial moisture in fruit slice} - \text{Moisture in osmosed fruit slice at time, } \theta}{\text{Initial weight of fruit slice}} \times 100$$

$$= \frac{(m_o X_{wo} - m_\theta X_{w\theta})}{m_o} \times 100 \quad (1)$$

$$SG = \frac{\text{Solids in osmosed fruit slice at time, } \theta - \text{Initial solids in fruit slice}}{\text{Initial weight of fruit slice}} \times 100$$

$$= \frac{m_\theta(1 - X_{w\theta}) - m_o(1 - X_{wo})}{m_o} \times 100 \quad (2)$$

where, WL is Water loss (%), SG is Solid gain (%), m_o is mass of jackfruit slices at time zero (g), m_θ is mass of jackfruit slices at time θ (g), X_{wo} is moisture content as a fraction of the mass of jackfruit slices at time zero (%), $X_{w\theta}$ is moisture content as a fraction of the mass of jackfruit slices at time θ (%).

Optimization of process parameters

Response surface methodology (Singh *et al.* 2007) [10] was used to optimize the experimental design shaped by CCRD. The CCRD offered 20 treatments wherein the focus was majorly on the central value of the given input process parameters. Optimization data were fitted to the second order polynomial equation, which described the effect of test variables (X_1, X_2, X_3) on the response 'Y' as well as the combined effect of all the test variables on the response 'Y' and determined the interrelationship among the test variables.

$$Y_i = \beta_0+\beta_1X_1+\beta_2X_2+ \beta_3X_3+\beta_{11}X_1^2 +\beta_{22}X_2^2+\beta_{33}X_3^2 +\beta_{12}X_1X_2+ \beta_{13}X_1X_3+\beta_{23}X_2X_3+ \varepsilon \quad (3)$$

where, Y_i is the predicted responses for WL and SG, β_0 is estimated coefficient at the center point of the design, β_1, β_2, β_3 are linear coefficients, β_{11}, β_{22}, β_{33} are quadratic coefficients, β_{12}, β_{13}, β_{23} are interaction coefficients and ε is random error.

Osmotic dehydration process was optimized by response surface methodology (RSM) to determine the optimum levels of process parameters, such as osmotic solution concentration, solution temperature and immersion time maximizing WL and minimizing SG.

Results and Discussion

Physico-chemical analysis

The initial moisture content, TSS, pH and titratable acidity of the fresh fruit was 70% (wb), 28 °B, 5.2 and 2.4 respectively.

Mass transfer parameters

The mass transfer parameters i.e. water loss and solid gain was tabulated in Table 1. Sampling was done in triplicate, mean values were noted.

Table 1: Water loss and solid gain responses for 20 treatments

Sl No.	Osmotic solution concentration, °B	Solution temperature, °C	Immersion time, min	Water loss, %	Solid gain, %
1	40(-1)	40 (-1)	60 (-1)	12	1
2	60 (+1)	40 (-1)	60 (-1)	16	2
3	40(-1)	60 (+1)	60 (-1)	17	2
4	60 (+1)	60 (+1)	60 (-1)	20	4
5	40(-1)	40 (-1)	180 (+1)	28	12
6	60 (+1)	40 (-1)	180 (+1)	29	13
7	40(-1)	60 (+1)	180 (+1)	29	13
8	60(+)	60 (+1)	180 (+1)	35	13
9	33(-1.682)	50 (0)	120 (0)	16	4
10	67(+1.682)	50 (0)	120 (0)	30	8
11	50 (0)	33 (-1.682)	120 (0)	14	7
12	50 (0)	67 (+1.682)	120 (0)	29	9
13	50 (0)	50 (0)	19 (-1.682)	15	2
14	50 (0)	50 (0)	221 (+1.682)	33	14
15	50 (0)	50 (0)	120 (0)	25	5
16	50 (0)	50 (0)	120 (0)	25	5
17	50 (0)	50 (0)	120 (0)	25	4

18	50 (0)	50 (0)	120 (0)	25	5
19	50 (0)	50 (0)	120 (0)	25	5
20	50 (0)	50 (0)	120 (0)	25	6

Water loss

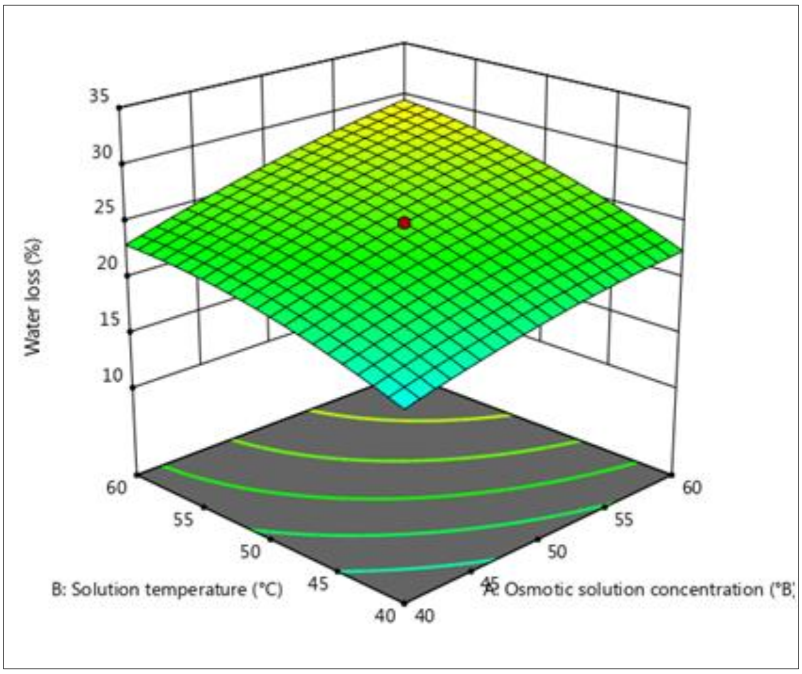
The water loss varied from a minimum of 12% to maximum of 35% respectively (Table 1). Table 2 indicated that model was significant.

Table 2: Anova and regression coefficients of dependent variables for water loss (WL) and solid gain (SG)

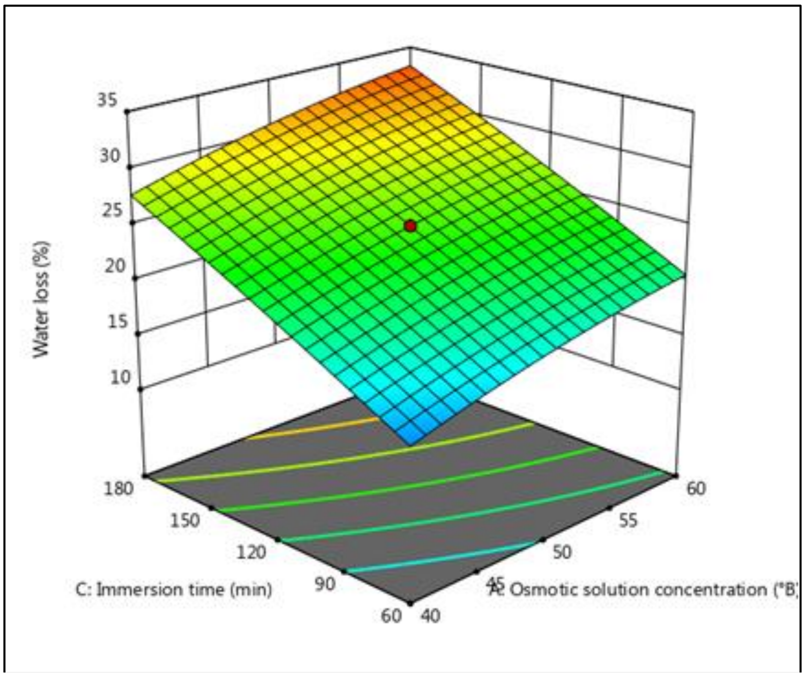
Source	Df	Water loss			Solid gain		
		Sum of squares	**p-value**	**Regression coefficient**	**Sum of squares**	**p-value**	**Regression coefficient**
Model	9	796.76	< 0.0001[a]		326.72	< 0.0001[a]	
Intercept				24.9823			4.99919
A	1	103.22	0.0014	2.74918****	8.43	0.0315	0.785479****
B	1	124.45	0.0007	3.01877****	3.97	0.1169	0.539186**
C	1	544.99	< 0.0001	6.31714****	283.12	< 0.0001	4.55314****
AB	1	2.00	0.5556	0.5**	0.0000	1.0000	-1.84E-16**
AC	1	0.00	1.0000	-2.44E-15**	0.5000	0.5562	-0.25**
BC	1	0.50	0.7667	-0.25**	0.5000	0.5562	-0.25**
A^2	1	5.04	0.3558	-0.59145**	1.86	0.2679	0.358856**
B^2	1	18.13	0.0962	-1.12178***	16.38	0.0059	1.06596****
C^2	1	0.8156	0.7052	-0.23789**	16.38	0.0059	1.06596****
Residual	10	53.79			13.48		
Lack of Fit	5	53.79			11.48	0.0389	
Pure Error	5	0.00			2.00		
Cor Total	19	850.55			340.20		

[a] – Significant, A: Osmotic solution concentration, B: Solution temperature, C: Immersion time
****$p < 0.05$, $0.05 \leq$ ***$p < 0.1$, **$p \geq 0.1$

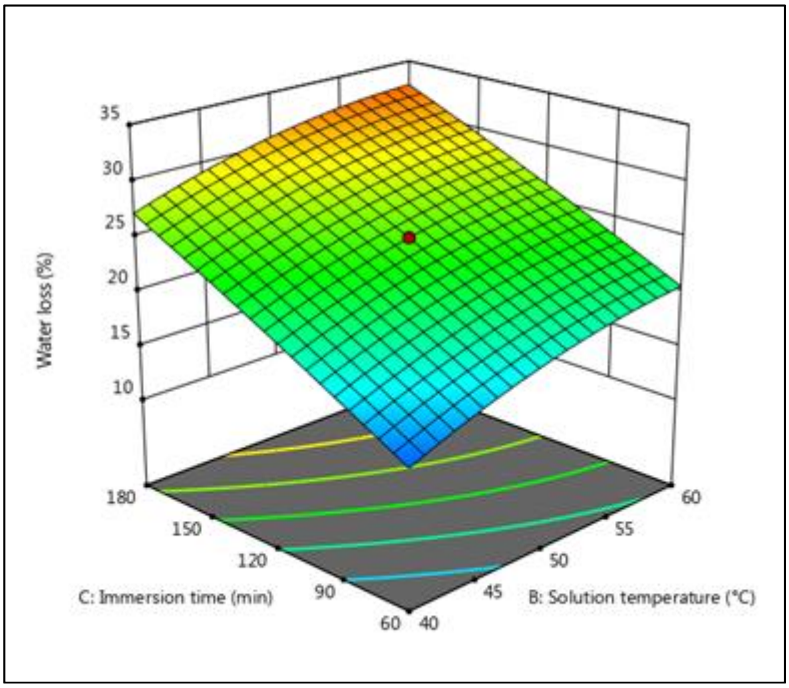
The coefficient of determination (R^2) was 0.9368. All the three process parameters showed positive significant effect on WL ($p < 0.05$) at linear level. All process parameters showed non-significant effect on water loss at interaction level, but the osmotic solution concentration-solution temperature showed positive effect and the other two interactions showed negative effect on WL. Osmotic solution concentration, solution temperature and immersion time showed negative non-significant effect at quadratic level. The response surface plots for WL in relation to osmotic solution concentration - solution temperature, osmotic solution concentration - immersion time and solution temperature - immersion time are shown in Fig. 1.



(a) Osmotic solution concentration *v/s* solution temperature



(b) Osmotic solution concentration *v/s* immersion time



(c) Osmotic solution temperature *v/s* immersion time

Fig 1: Response surface plots showing effect of process parameters on water loss (WL)

Continuous increase in the WL was observed as the immersion time increased, at a specific concentration and with increase in concentration from 40 to 60 °B at constant time, the water loss again increased (Fig. 1(a)) which were compatible with Park *et al*. (2002). WL showed positive interaction effect of immersion time and osmotic solution concentration. Increase in the osmotic solution concentration showed increase in WL in the initial stages but later the water loss increased in a completely decreasing trend due to the solid gain in the jackfruit slices. These results are in agreement with Rahman and Lamb (1990). The interaction effects of temperature and concentration showed increasing effect on WL. Interaction effects of time and temperature showed cumulative effect (Fig. 1(c)). This indicates increase in WL with increase in solution temperature at specific immersion time. However, this increase was less pronounced when immersion time was increased to 180 min (Fig. 1(c)). The least prominent increase in WL at increased solution temperature maintained for longer immersion time details that further increase in solution temperature affects the permeability and reduces the osmotic rate. This might be due to reduction in viscosity of osmotic solution and increase in water diffusion coefficient at high solution temperature. When immersion time was increased at a constant temperature, there was again an increase in water loss which is in agreement with Singh *et al*. (2007) [10].

Final equation in terms of actual factors for water loss

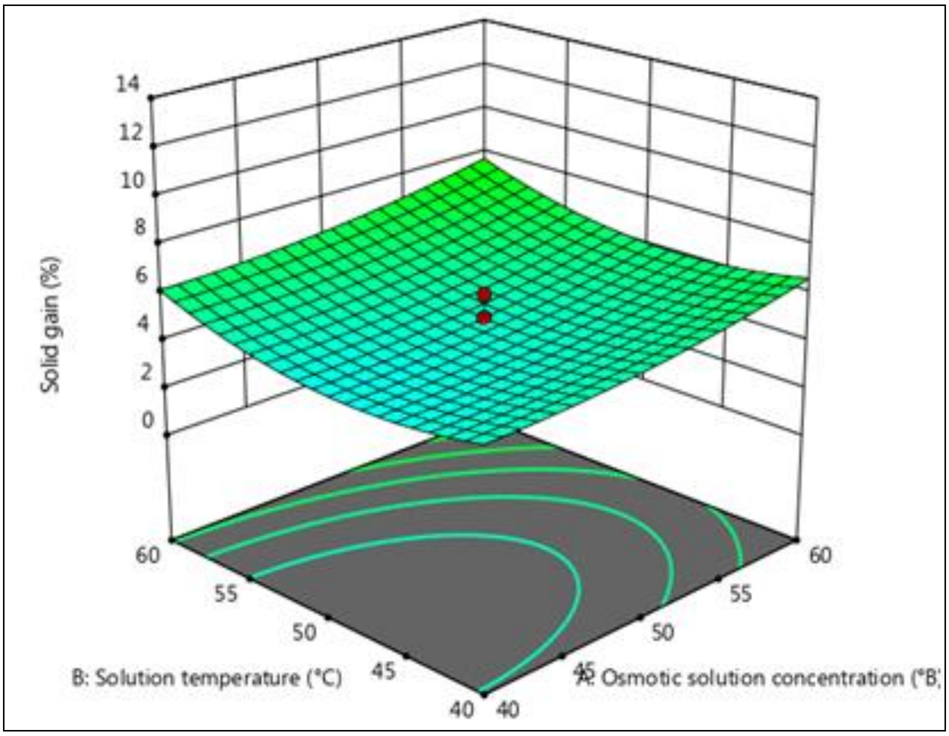
Water loss (WL) = -50.27378 + (0.616363 × A) + (1.22365 × B) + (0.141978 × C) + (0.005000 × A × B) + (-1.47079E-17 ×

$A \times C) + (-0.000417 \times B \times C) + (-0.005914 \times A^2) + (-0.011218 \times B^2) + (-0.000066 \times C^2)$

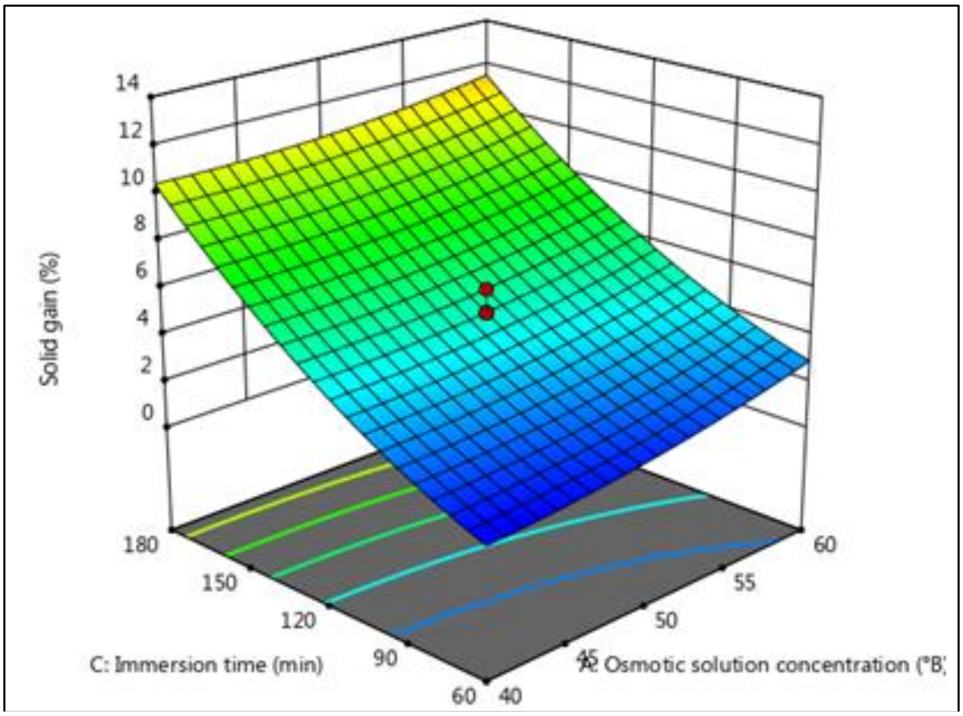
Where, A is osmotic solution concentration, B is solution temperature, C is immersion time.

Solid gain

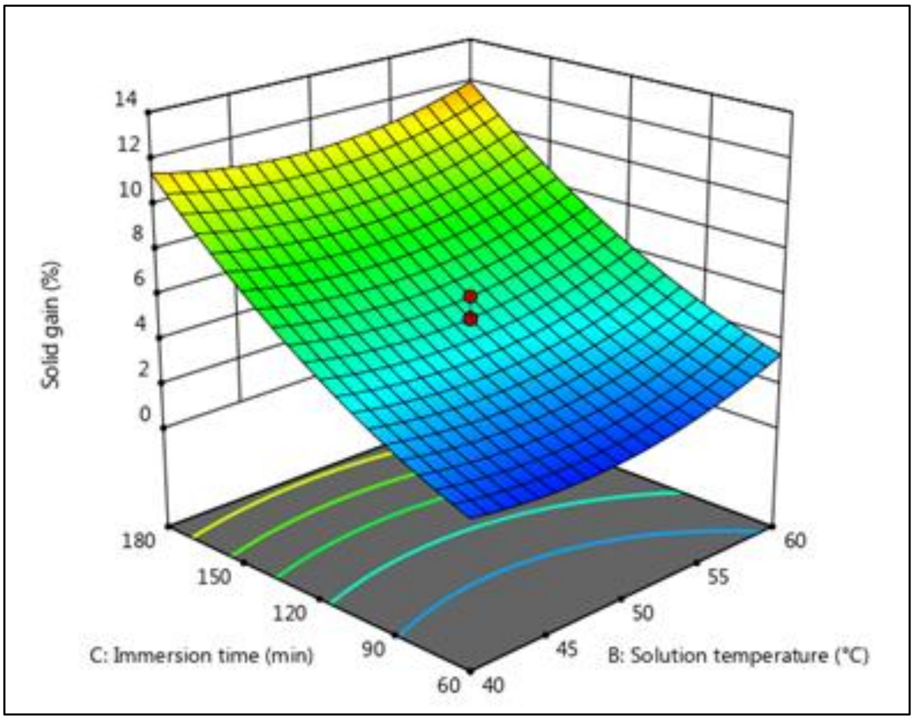
Solid gain varied from a minimum of 1% to a maximum of 14% (Table 1). Table 2 indicated that the model was significant. The coefficient of determination (R^2) was 0.9604. The response surface plots for SG in relation to osmotic solution concentration- solution temperature, osmotic solution concentration - immersion time and solution temperature - immersion time are shown in Fig. 2.



(a) Osmotic solution concentration *v/s* solution temperature



(b) Osmotic solution concentration *v/s* immersion time



(c) Osmotic solution temperature *v/s* immersion time

Fig 2: Response surface plots showing effect of processing parameters on solid gain (SG)

The regression coefficients of osmotic solution concentration, immersion time (Table 2) highlighted that the SG affected significantly positive at linear level and regression coefficient of solution temperature had positive non-significant effect on SG during the osmotic dehydration. Interactions were negative and non-significant in terms of SG. Osmotic solution concentration showed positive but non-significant effect whereas solution temperature and immersion time had a positive significant effect ($p < 0.05$) at the quadratic level. SG increased with immersion time and temperature, and less pronounced effect on solution concentration. The increased concentrations caused extreme mass transfer with prominence on SG (Bohuon *et al*. 1998) [4].

The water loss and solid gain ranged from 32-49.2%, 2.3-3.1% for aonla slices (Alam *et al.* 2010) [1], 40-64.8%, 3.6-9.3% for potato cubes (Eren and Kaymak-Ertekin 2007) [5], 23.2-44.5%, 3.0-8.2% for papaya cubes (Jain *et al*. 2011), 17.5-28.2%, 3.4-7.0% for guava slices (Vieira *et al*. 2012) [11].

Final equation in terms of actual factors for solid gain

Solid gain (SG) = +24.15389 + (-0.230308 × A) + (0.962044 × B) + (0.046488 × C) + (-5.29379E-17 × A × B) + (-0.000417 × A × C) + (-0.000417 × B × C) + (0.003589 × A^2) + (0.010660 × B^2) + (0.000296 × C^2)

Where, A is osmotic solution concentration, B is solution temperature, C is immersion time.

Optimization of process parameters

The process parameters were optimized by set goals and by the importance given to them as shown in the Table 3.

Table 3: Constraints, goal, criteria for optimization and importance

Constraints	Goal	Lower Limit	Upper Limit	Importance
A:Osmotic solution concentration	is in range	40	60	3
B:Solution temperature	is in range	40	60	3
C:Immersion time	is in range	60	180	3
Water loss	maximize	12	35	5
Solid gain	minimize	1	14	1

Numerical optimization gave the solutions of WL and SG as 33.1 % and 10.2 % respectively. The process parameters contributed are 60 °B of osmotic solution concentration, 57 °C of solution temperature and 160 min of immersion time.

Conclusions

Response surface methodology optimized the process parameters during osmotic dehydration of jackfruit bulb slices by maximizing water loss (WL) and minimizing solid gain (SG). All the three input process parameters used in the study showed significant effects on the responses i.e. water loss and solid gain. An optimized condition for the process variables were arrived at 60 °B of osmotic solution concentration, 57°C of solution temperature and 160 min of immersion time respectively. Optimized process parameters results in a superior quality product.

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