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Studies on mass transfer parameters during osmotic dewatering process of jackfruit bulb slices

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Abstract
Osmotic solution concentration of 40-60 °B, osmotic solution temperature of 40-60 °C and immersion time of 60-180 min were the three process parameters (independent variables) engaged for osmotic dewatering process of jackfruit bulb slices. The fruit to osmotic solution ratio was taken as 1:4. Water loss (WL), solid gain (SG) and water loss-solid gain ratio (WL/SG) were the mass transfer parameters (dependent variables) studied during osmotic dewatering process. The water loss ranged from a minimum of 12% to a maximum of 35%, solid gain ranged from a minimum of 1% to a maximum of 14% and water loss-solid gain ratio ranged from a minimum of % to a maximum of % respectively.

Keywords: Jackfruit bulb slices, central composite rotatable design (CCRD), osmotic solution, osmotic dewatering process (ODP), mass transfer parameters

Introduction
Osmosis is the partial water removal process or partial dewatering process from biological materials by immersion in concentrated sugar or salt solutions. Advantages of osmotic dewatering process are abridged weight, least heat damage, reduced discolouration of biological materials and a ready to eat product without rehydration (Ramya and Jain, 2016) [16].
Jackfruit (*Artocarpus heterophyllus* L.) is a species of the mulberry family (Moraceae). Major producers of jackfruit in the world are 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) [9]. It was reported in India that nearly three-fourths of total jackfruit produced gets spoiled because of improper preservation and storage facilities (Anonymous, 2013) [1].
Jackfruit fights against cancer, increases immunity in humans, assists in healthy digestion, upholds a healthy eye and skin, boosts energy, reduces high blood pressure, controls asthma, strengthens the bone, avoids anaemia and keeps a healthy thyroid. Jacalin, a chemical obtained from jackfruit helps in averting colon cancer and AIDS (Devi *et al*., 2014) [7]. 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. Fruit can be formulated to alcoholic liquor (Elevitch and Manner, 2006) [8]. Ripened pulp of jackfruit is dried and ground into powder to flavour drinks (Clarke *et al*., 2011) [6].
A good combination of process parameters results in greater mass transfer parameters. A study was conducted to determine the mass transfer parameters, wherein, the effects of process parameters i.e., osmotic solution concentration, osmotic solution temperature and immersion time on osmotic dewatering process of jackfruit bulb slices were studied.

Materials and Methods
Raw Material
Matured jackfruits (firm variety) were obtained from local market. Jackfruits were washed in water to exclude dirt or dust adhered to it. The jackfruits were cut manually using a 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

The moisture content of fresh slice was determined by AOAC (2005). Total soluble solids (TSS) were measured by hand refract to meter (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) [13]. Sampling was done in triplicate, mean values were noted.

Experimental Design

Inorder to reduce the number of experiments, usage of statistical software was undergone. Central composite rotatable design (CCRD) was taken. In this design, the total number of experiments (N) were determined.
Required number of experiments n_f is given by,

$$n_f = V^k \quad ...(1)$$

Where, k is the number of independent variables
V is the number of levels
An assumption was made that a linear relationship exists between independent and dependent variables.
Value a_m of the coded variable x is fixed at,

$$a_m = (2^{(\text{number of variables})})^{0.25} \quad ...(2)$$

Thus, for three independent variables $a_m = (2^{(3)})^{0.25} = 1.682$
For three variables, the range is +1.682 and -1.682. Number of experiments, n_a to be carried out $+a_m$ and $-a_m$ is given by,

$$n_a = 2k \quad ...(3)$$

Where, k is the number of independent variables.
In order to find out the significance of developed model for its adequacy in relating response 'y' and independent variable 'x', 'pure experimental error' was determined. For that, certain additional experiments were carried out at the 'center point', where the coded values of 'x' are zero. According to CCRD minimum number of experiments, n_c that are required to be carried out at the 'center point' have been found out as (Myers, 1971),

$$n_c = 6 \text{ when } k = 3 \quad ...(4)$$

Thus, the total number of experiments calculated by,

$$N = n_f + n_a + n_c \quad ...(5)$$

$$N = 8 + 6 + 6 = 20 \quad ...(6)$$

Osmotic solution concentration of 40-60 °B, osmotic 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 (Table 1). Design gave 20 experiments (Roopa 2012) consisting of coded and real values (Table 2).

Table 1: Levels, codes and interval variations of independent independent process parameters

Independent process parameters	Units	Coded levels of x_1, x_2 & x_3					Interval variation
		-1.682	-1	0	+1	+1.682	
Osmotic solution concentration, x_1 (° B)	˚B	33	40	50	60	67	10
Osmotic solution temperature, x_2	˚C	33	40	50	60	67	10
Immersion time, x_3	min	19	60	120	180	221	30

Table 2 Central composite rotatable design (CCRD) for three independent variables and their coded and real values

S No.	Coded values			Real values		
	Osmotic solution Concentration (x_1)	Osmotic solution temperature (x_2)	Immersion Time (x_3)	Osmotic solution Concentration (x_1)	Osmotic solution Temperature (x_2)	Immersion Time (x_3)
1	-1	-1	-1	40	40	60
2	1	-1	-1	60	40	60
3	-1	1	-1	40	60	60
4	1	1	-1	60	60	60
5	-1	-1	1	40	40	180
6	1	-1	1	60	40	180
7	-1	1	1	40	60	180
8	1	1	1	60	60	180
9	-1.682	0	0	33	50	120
10	1.682	0	0	67	50	120
11	0	-1.682	0	50	33	120
12	0	1.682	0	50	67	120
13	0	0	-1.682	50	50	19
14	0	0	1.682	50	50	221
15	0	0	0	50	50	120
16	0	0	0	50	50	120
17	0	0	0	50	50	120
18	0	0	0	50	50	120
19	0	0	0	50	50	120
20	0	0	0	50	50	120

Preparation of Osmotic Solutions

Commercial 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 stainless steel containers containing different concentrations of osmotic sugar 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).

Mass Transfer Parameters

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

$$\mathrm{WL} = \frac{\text{Initial moisture in fruit slice} - \text{Moisture in osmosed fruit slice at time, }\theta}{\text{Initial weight of fruit slice}} \times 100 = \frac{(m_o X_{wo} - m_\theta X_{w\theta})}{m_o} \times 100 \quad (7)$$

$$\mathrm{SG} = \frac{\text{Solids in osmosed fruit slice at time, }\theta - \text{Initial solids in fruit slice}}{\text{Initial weight of fruit slice}} \times 100 = \frac{m_\theta(1 - X_{w\theta}) - m_o(1 - X_{wo})}{m_o} \times 100 \quad (8)$$

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 (%).

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, solid gain and water loss-solid gain ratio were tabulated in Table 3. Sampling was done in triplicate, mean values were recorded. The water loss varied from a minimum of 12% to maximum of 35%, solid gain varied from a minimum of 1% to a maximum of 14% and water loss-solid gain ratio varied from a minimum of 2% to a maximum of 12% respectively. To be a good osmotic dewatering process the water loss should be high, solid gain should be low and the water loss-solid gain ratio should be high. This is the essential criteria for a good osmotic dewatering process.

Analyzing the data in Table 3, the increase in osmotic solution concentration resulted in increase of osmotic pressure which drives the osmosis process, hence, higher water loss values were observed throughout the osmotic dewatering process. These results indicate preferring higher concentration osmotic solutions benefits in faster water loss and could be achieved effortlessly. However, the increase in osmotic solution temperature resulted in increased water loss. But, the quality parameters are compromised at higher osmotic solution temperatures. The majority of the water loss occured in the initial immersion time of approx. 150 min which indicates increase in the immersion time increased the water loss, but, after a period of time, there is a decrease in water loss with increase in immersion time, and in some cases it is considered no effect.

These results are in agreement with Kiwiberry (Bialik *et al.*, 2018) [5], pineapple (Zahoor and Khan, 2017) [15], cherry tomato (Azoubel and Murr, 2004) [4] respectively.

Table 3: Water loss, solid gain and water loss-solid gain ratio responses for 20 treatments

S. No.	Osmotic solution concentration, °B	Osmotic solution temperature, °C	Immersion time, min	Water loss, %	Solid gain, %	WL/SG ratio
1	40(-1)	40 (-1)	60 (-1)	12	1	12
2	60 (+1)	40 (-1)	60 (-1)	16	2	8
3	40(-1)	60 (+1)	60 (-1)	17	2	9
4	60 (+1)	60 (+1)	60 (-1)	20	4	5
5	40(-1)	40 (-1)	180 (+1)	28	12	2
6	60 (+1)	40 (-1)	180 (+1)	29	13	2
7	40(-1)	60 (+1)	180 (+1)	29	13	2
8	60(+)	60 (+1)	180 (+1)	35	13	3
9	33(-1.682)	50 (0)	120 (0)	16	4	4
10	67(+1.682)	50 (0)	120 (0)	30	8	4
11	50 (0)	33 (-1.682)	120 (0)	14	7	2
12	50 (0)	67 (+1.682)	120 (0)	29	9	3
13	50 (0)	50 (0)	19 (-1.682)	15	2	8
14	50 (0)	50 (0)	221 (+1.682)	33	14	2
15	50 (0)	50 (0)	120 (0)	25	5	5
16	50 (0)	50 (0)	120 (0)	25	5	5
17	50 (0)	50 (0)	120 (0)	25	4	6
18	50 (0)	50 (0)	120 (0)	25	5	5
19	50 (0)	50 (0)	120 (0)	25	5	5
20	50 (0)	50 (0)	120 (0)	25	6	4

Conclusions

The mass transfer parameters like water loss, solid gain, water loss-solid gain ratio were studied. The influence of input process parameters i.e., osmotic solution concentration, osmotic solution temperature, immersion time on the mass transfer parameters like water loss, solid gain, water loss-solid gain ratio were studied. Input process parameters have positive effect on the mass transfer parameters. The water loss, solid gain, water loss-solid gain ratio ranged from 12-35%, 1-14%, 2-12% respectively. From this it can be concluded that the osmotic dewatering process has been achieved at expected level. These mass transfer parameters helps in understanding the osmotic dewatering process and help food technocrats and food engineers to design, develop on-farm osmotic treatment systems to process the produce, so that in glut seasons, they generate income to the farmers and they can sell their produce at hiked prices in the form of Ready to Eat (RTE) processed food instead of selling raw afresh.

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