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Mass Transfer Kinetics of Osmotic Dehydration of Pineapple

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Abstract

Current study deals with the kinetics and mathematical modelling of osmotic dehydration of pineapple. Pineapple (*Ananas comosus)*, 10 mm thick slices weighing 50 g each, was studied for the osmotic dehydration using hypertonic solutions of sucrose and fructose. The osmotic dehydration process was performed using three levels of temperature 40°C, 50°C and 60°C, three levels of osmotic solution concentration (40%, 50% and 60%) with sample to solution ratio maintained at 1:4, 1:5 and 1:6 respectively. After each interval of time, moisture loss and solid gain was recorded. It was found that moisture loss and solid gain increased with increase in osmotic temperature and osmotic solution concentration. The highest mass transfer was observed at concentration of 60% and temperature of 60°C. Three models (Handerson and Pabis model, Logarithmic model and Lewis model) were used to analyze osmotic dehydration data. Among the three models, Logarithmic model showed a best fit to the osmotic dehydration data with higher value of coefficient of determination (R^2).

Keywords: Osmotic dehydration; Mass transfer kinetics; Pineapple; Solid gain; Moisture loss

Introduction

Pineapple, also known as Queen of fruits is one of the important commercial fruit crops in the world [1]. The fruit is known for its exceptional juiciness, excellent flavor, taste and numerous health benefits. The fruit is highly perishable containing about 14% of sugar, good amount of vitamin A and B, citric acid, malic acid and bromelin [2]. The bromelin, a protein digesting enzyme, aids in the digestion of proteins when taken with meals [3]. Various food items like squash, syrup, jelly are produced from pineapple. Vinegar, alcohol, citric acid, calcium citrate etc. are also produced from pineapple. Pineapple is also recommended as medical diet for certain diseased persons [4]. Physically, the fruit is hard on the outside and soft on the inside and can be eaten raw or added to desserts and fruit salads. In addition to this, squash, syrup and jelly like food items are also made from pineapple. Thailand, Philippines, Brazil and china are the main pineapple producers in the world supplying nearly about 50% of the total output [5]. The commercial cultivation of pineapple in India is believed to be only four decades old and is largely grown in states like Assam, Meghalaya, Tripura, Sikkim, Mizoram, West Bengal, Kerala, Karnataka and Goa. Osmotic dehydration is basically a water removal process in which materials such as fruits are placed into a concentrated solution of soluble solutes. By doing this, a major part of water is removed from substance and time required for relatively high temperature air drying is reduced. Conventional air drying is energy intensive and cost intensive because it is simultaneous heat and mass transfer process accompanied by phase change [6]. Even though the pineapple is available round the year but there is some peak harvest season at which harvest is so abundant that some of the fruit has to be left in the field or sold at a very low price. One way to increase the value of this crop is by drying it. Conventional air drying may result in browning or caramelization of sugar due prolonged exposure to the heat. Osmotically pre drying pineapple would reduce this problem. The effects of sucrose concentration, processing time, temperature, slice thickness, fruit to syrup ratio on weight reduction and total soluble solids were studied by Singh et al. [7]. It was observed that percent weight reduction and total soluble solids increases with increase in sucrose concentration and temperature. It has been found that 60% sucrose solution at 50°C, 1:4 fruit to syrup ratio and 10 mm thickness give best results [7]. A significant amount of weight loss (47.40) within 4 hours of osmosis was showed by mango slices when osmosed in 67.4° brix of osmotic solution at 40°C having sample to solution ratio of 1:3.34 [8]. About 50% of water was removed from the 5 mm of banana slices when 63°brix sugar solutions was maintained at 75°C within one hour of osmosis and 57.9% of water was removed when slices were osmosed for 2.5 hours [9]. The specific objective of this work was to study the effect of osmotic solution concentration, sample to solution ratio and temperature on mass transfer of the osmotic dehydration of pineapple and to determine the best mathematical model that can describe the kinetics of osmotic dehydration process.

Materials and Methods

Raw material preparation

The experiments were conducted on fresh, ripe and good quality pineapples. The fully ripen pineapples were peeled manually, cored and then sliced into 10 mm thick slices and further divided into four pie wedge shaped pieces. To inactivate enzymes, pineapple slices were blanched at 80°C for a min [10]. Moisture content was determined by placing the samples in an oven at 100°C for 16 to 18 hours or till constant weight was achieved [11]. The samples were then subjected to osmotic dehydration treatment. Figure 1 shows the procedure involved in the osmotic dehydration treatment of the pineapple slices.

Osmotic dehydration treatment

The sucrose and fructose solution made with concentration levels of 40%, 50%, 60% with sample to solution ratio of 1:4, 1:5 and 1:6 respectively were used for each experiment. The samples weighing 50 g were used for each experiment and then immersed in osmotic solutions for 10, 20, 30, 40, 50, 60, 90, 120, 150, 180 and 240 min at a temperature of 40°C, 50°C, and 60°C. The temperature was controlled with hot

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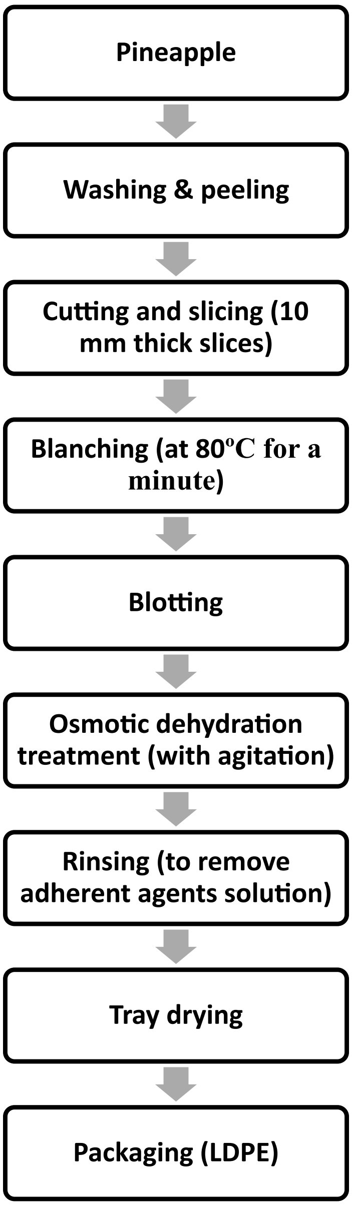

Figure 1: Procedure involved in osmotic dehydration of pineapple slices.

water bath. The sample/solution ratio was kept as 1:4, 1:5, and 1:6 [12]. After each interval of time moisture loss and solid gain were recorded. The osmotically dehydrated samples were then blotted dry with tissue paper and then weighed in weighing balance. The samples were then dried in tray dryer.

Determination of process parameters

The moisture content of the sample was found by using following equation [11]:

$$MC\ (\%\ w.b) = \frac{(initial\ weight - final\ weight)}{initial\ weight} \times 100 \quad (1)$$

The moisture loss during osmotic dehydration treatment was determined using the following equation [13,14]:

$$ML\ (\%) = \frac{(Wt\ of\ initial\ moisture(g) - Wt\ of\ final\ moisture(g))}{initial\ weight\ of\ sample\ in\ gms} \times 100 \quad (2)$$

The solid gain during osmotic dehydration treatment was determined by using following equation [13,14]:

$$SG\ (\%) = \frac{(Wt.of\ final\ solid\ (g) - Wt.of\ initial\ solid\ (g))}{initial\ wt\ of\ the\ sample\ in\ gms} \times 100 \quad (3)$$

Mass transfer kinetics

For determination of moisture and solid change during osmotic dehydration under different treatment, as a function of dehydration time, the rate of change of a quality factor C can be represented by:

$$\frac{dc}{dt} = -kC^n \quad (4)$$

Where C is the concentration of a quality factor at time t, k is the kinetic rate constant and n is the order of the reaction. For the majority of foods, the time–dependence relations appear to be described by zero order [15,16] or first order kinetic models [15,16], by integrating eq. (4), zero order eq.(5) and first order kinetic models eq. (6) can be derived as:

$$C = C_0 \pm kt \quad (5)$$

$$C = C_0 \exp\ (\pm kt) \quad (6)$$

Where C_0 is the initial value of mass transfer parameter and C is the mass transfer value at a specific time. In the equation, (±) indicates gain and loss of any mass transfer parameter.

Statistical analysis

The XLSTAT software package (XLSTAT evaluation version 2016) was used for regression analysis. The correlation coefficient (R^2) and RMSE were considered as the criteria for selecting the best equation. The higher the value of R^2 and the lower the value of RMSE, the better the model was taken to fit. By equation:

$$R^2 = \frac{\sum_{i=1}^{N} (C_{pre,i} - C_{pre,avg})^2}{\sum_{i=1}^{N} (C_{evp,i} - C_{evp,avg})^2} \quad (7)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (C_{pre,i} - C_{evp,i})}{N}} \quad (8)$$

Where, $C_{exp,i}$ is the i[th] experimental value, $C_{exp,i}$ is the i[th] predicted value and N is the total number of observations in particular model.

Mathematical modeling

Following formulae were used for calculation of moisture ratio (MR) during osmotic dehydration experiment.

$$MR = \frac{[Mt - Me]}{[Mi - Me]} \quad (9)$$

Where,

MR is the moisture ratio.

M_t = Moisture content at any time, t

M_i = initial moisture content.

M_e = Equilibrium moisture content (at the end of drying).

The following drying models were used for osmotic dehydration data:

a. Handerson and Pabis model:

$$MR = exp(-kt) \tag{10}$$

b. Logarithmic model:

$$MR = a.exp(-kt) + c \tag{11}$$

c. Lewis model:

$$MR = exp(-kt) \tag{12}$$

Results and Discussion

The specific objective of this research was to examine the effect of osmotic temperature, osmotic solution concentration and sample to solution ratio on osmotic dehydration behavior of pineapple slices. Three models (Handerson and Pabis model, Logarithmic Model, Lewis model) were used for osmotic dehydration data. The results are presented below.

Mass transfer kinetics during osmotic dehydration of pineapple

The experiments were carried out at osmotic solution concentration of 40%, 50% and 60%, osmotic temperature of 40°C, 50°C and 60°C and sample to solution ratio of 1:4, 1:5 and 1:6, respectively. To study the osmotic kinetics at each experimental condition, the osmotic dehydration treatment was carried out from 10 to 240 min with varying time interval.

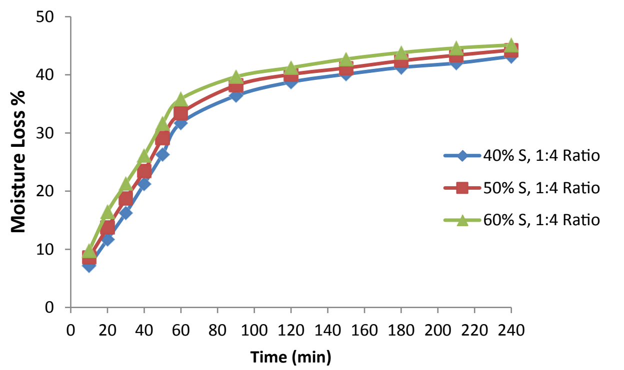

Figure 2: Effect of osmotic concentrations of sucrose on moisture loss of pineapple at 40°C and 1:4 sample to solution ratio.

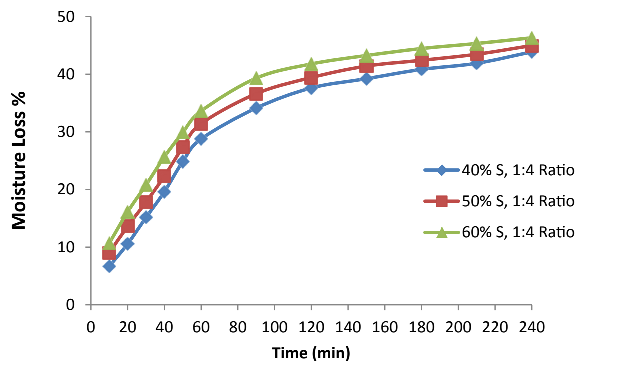

Figure 3: Effect of osmotic concentrations of sucrose on moisture loss of pineapple at 60°C and 1:4 sample to solution ratio.

Model	Sucrose		Fructose	
	R^2	RMSE	R^2	RMSE
Zero order: $C = C_0 \pm kt$	0.838	5.203	0.854	6.865
First order: $C = C_0\, exp\ (\pm kt)$	0.743	5.857	0.762	7.891

Table 1: R^2 and RMSE values of zero and first order kinetic models for moisture loss.

Effect of osmotic solution concentration, osmotic temperature and sample to solution ratio on moisture loss of pineapple slices during osmotic dehydration treatment

Plots for moisture loss verses dehydration time as shown in Figures 2 and 3 shows the effects of osmotic solution concentration and osmotic temperature on moisture loss of pineapple samples. The plots showed that the moisture loss increased in a nonlinear mannered with time at all concentration of sucrose at different temperatures. Similar results have been obtained for experimental data for fructose. It was found that moisture loss increased with increase in temperature from 40°C to 60°C. Similar results were reported by Rahman and Lamb [17]. It was also observed that moisture loss was faster during initial period of osmotic dehydration and then rate decreased. During osmotic dehydration treatment moisture loss after 240 min in sucrose solution was found to be 39.079% to 46.32% of initial weight of pineapple samples. However, moisture loss after 240 min of osmotic dehydration in fructose solution was found to be 39.079% to 45.385% of initial weight of pineapple samples.

Kinetic models for moisture loss

For the mass transfer kinetics, zero order and first order kinetic models were used during osmotic dehydration of pineapple in sucrose. From the Table 1 it can be seen that the data for the moisture loss fitted to zero order kinetic model compared to the first order kinetic model with high values of coefficient of determination (R^2) and low values of root mean square error (RMSE) as shown by mass transfer kinetic studies.

Effect of osmotic solution concentration, osmotic temperature and sample to solution ratio on solid gain of pineapple slices

Solid gain of osmotic dehydrated pineapple slices were calculated in order to determine the amount of solute penetrated during osmotic dehydration process from the osmotic solution. The effect of osmotic solution concentration of sucrose on solid gain of pineapple samples at 40°C and 60°C temperature having sample to solution ratio of 1:6 with respect to time are shown in Figures 4 and 5. From the graphs, it can be observed that solid gain increased nonlinearly with time. Moreover, it was also found that solid gain increased in the initial period of osmotic dehydration treatment and then rate decreased. It was also found that the solid gain increased with increase in temperature from 40°C to 60°C.

Kinetic models for solid gain

For the mass transfer kinetics during osmotic dehydration of pineapple slices, zero order and first order kinetics models were also used. It was found that the data for solid gain was fitted to zero order kinetic model compared to the first order kinetic model with high values of coefficients of determination and low value of root mean square error (RMSE) as shown in Table 2.

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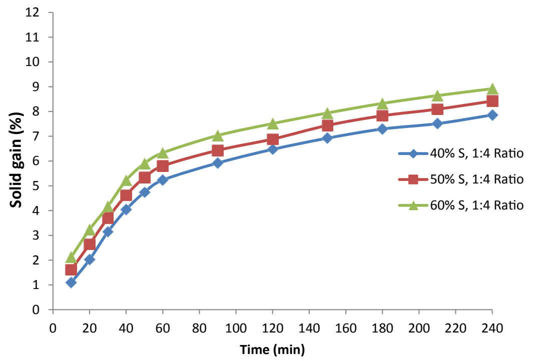

Figure 4: Effect of osmotic concentrations of sucrose on solid gain of pineapple at 40°C and 1:4 sample to solution ratio.

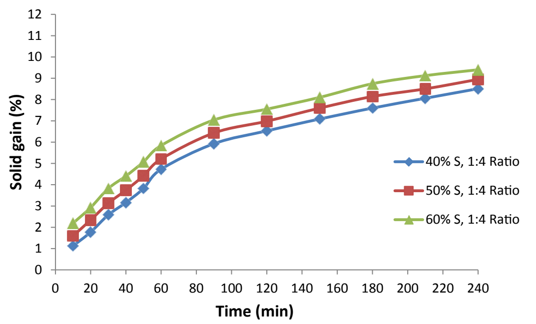

Figure 5: Effect of osmotic concentrations of sucrose on solid gain of pineapple at 60°C and 1:4 sample to solution ratio.

Model	Sucrose		Fructose	
	R^2	RMSE	R^2	RMSE
Zero order: $C = C_0 \pm kt$	1.00	0.00	0.852	0.901
First order: $C = C_0 \exp(\pm kt)$	0.854	0.907	0.770	1.081

Table 2: R^2 and RMSE values of zero and first order kinetic models for solid gain.

Osmotic agent	Models					
	Handerson and Pabis model $MR = a.exp(-kt)+c$		Logarithmic model $MR = a.exp(-kt)+c$		Lewis model $MR = exp(-kt)$	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
Sucrose	0.995	0.052	0.998	0.050	0.993	0.079
Fructose	0.997	0.046	0.999	0.047	0.997	0.067

Table 3: R^2 and RMSE values of different models.

Validity of models

Three models i.e. Handerson and Pabis model [18], Logarithmic model [19], and Lewis model [20], were tested to select the best model. In the proposed drying models, the moisture ratio (MR) is a nonlinear function of time. Nonlinear regression modelling of experimental data was carried out to obtain the values of constants of these models. The correlation coefficient (R^2) and RMSE were considered as the criteria for selecting the best equation. The models were fitted to the experimental data using XLSTAT. The R^2 and RMSE values for each of the tested models are given in Table 3.

From the Table 3 it can be seen that, for the Handerson and Pabis model, the R^2 was found to be 0.995 using sucrose as an osmotic agent and 0.997 for fructose while as RMSE was found to be 0.052 for sucrose and 0.046 for fructose which indicates good fit of the Handerson and Pabis model. For logarithmic model, the R^2 was found to be 0.998 using sucrose as an osmotic agent and 0.999 for fructose while as RMSE was found to be 0.050 for sucrose and 0.047 for fructose which indicates the best fit of the logarithmic model as shown in Table 3. Similarly for the Lewis model , the R^2 was found to be 0.997 using sucrose as an osmotic agent and 0.993 for fructose while as RMSE was found to be 0.079 for sucrose and 0.067 for fructose which indicates a good fit of the Lewis model (Table 3) Thus, Logarithmic model is the most acceptable one and fits best to the given set of experimental data for osmotic dehydration of pineapple.

Conclusion

On the basis of the finding of the present study it can be concluded that there was remarkable effect of osmotic solution concentration, osmotic temperature and sample to solution ratio on osmotic dehydration of pineapple slices. It was found that moisture loss and solid gain increased with increase in osmotic solution concentration from 40% to 60%. Temperature was found to have proportional effect on moisture loss and solid gain. Both the moisture loss and solid gain were higher during initial period of osmotic dehydration treatment than in the later period. Both the data for moisture loss and solid gain were fitted to zero order kinetic model compared to a first order kinetic model with high value of coefficient of determination. Among the three models that were used Logarithmic model showed a best fit to the experimental data of osmotic dehydration with higher value of coefficient of determination and low values of RMSE.

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