

Elephant Foot Yam (*Amorphophallus paeoniifolius*): Osmotic Dehydration and Modelling

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Abstract

Osmotic dehydration of elephant foot yam was done in different concentration of sucrose solution at different temperature for regular interval of time. The osmotic solution concentrations used were 40, 50, 60°Bx, osmotic solution temperatures were 35, 45, 55°C and the process duration varied from 0 to 240 min. The fruit to solution ratio was kept constant i.e. 1:5 (w/w) during all the experiments. The experimental data of water loss and solute gain was fitted to different empirical kinetic models viz. Peleg, Penetration, Magee, and Azuara to know the best fitted model to the experimental data. Out of all the applied models, Magee model and Azuara model were the best fitted as compared to other models for water loss and solute gain of elephant foot yam, respectively.

Keywords: Elephant foot yam; Osmotic dehydration; Kinetics; Empirical models

Introduction

Elephant foot yam, *Amorphophallus paeoniifolius* is very much prevalent in Philippines, India, Malaysia, Indonesia, China, Sri Lanka and many other Southeast Asian countries [1]. The tubers of elephant foot yam are commonly used as a vegetable after cooking and in preparation of indigenous ayurvedic medicines [2]. The tubers are cheapest source of carbohydrates mainly starch and fibres, vitamins and minerals [3] and play an important role in food security and are the important staple or subsidiary food for a large group of population [4]. Tubers have a short shelf life because of their high moisture content. One of the best ways to preserve them may be by processing methods like drying, dehydration or by obtaining flour and/or starches. Due to the reduction of moisture content by various means the shelf life of corms can be increased. In recent years, for preservation of fruits and vegetables osmotic dehydration technique is gaining considerable amount of attention due to its potential to keep sensory and nutritional properties similar to the fresh fruits [5]. Osmotic dehydration is the process of water removal by immersion of water containing cellular solid in a concentrated aqueous solution of high osmotic pressure (hypertonic media) for a specified time and temperature. Water removal in osmotic dehydration is based on the natural and non-destructive phenomenon of osmosis across cell membranes. The driving force for water removal from cell is potential difference between osmotic pressure of fresh material and surrounding solution [6]. Osmotic dehydration is actually combination of simultaneous water and solute diffusion process [7] means mass transfer consists of two major simultaneous counter-current fluxes of water and solutes because complex cell wall structure is not perfectly selective [8]. Leaching of negligible amount of natural solutes from food into solution has considered as third minor flux [9]. This pre-treatment minimize color losses as well as reduce nutrient losses due to drying. The influence of the main process variables such as concentration and composition of osmotic solution, temperature, immersion time, pre-treatments, agitation, nature of food and its geometry, solution to sample ratio on the kinetics of mass transfer and product quality have been studied extensively [10,11]. Considerable effort has been made toward developing models to predict the mass transfer kinetics of osmotic dehydration process. In this regard, several equations based on Fick's second law have been proposed which are not useful practically because of unrealistic assumptions and complexity of the some equations. Some researchers like Peleg [12], Azuara

[13], Magee et al. [14] and Rahman [15] etc. recommended simpler empirical equations including parameters with physical meaning. These empirical equations have been used to model the rate of dehydration of different plant-based materials [16-21]. However, literature about the suitability of these equations to model the mass transfer kinetics of osmotically dehydrated elephant foot yam is very rare. So, the aim of present study was to evaluate the effect of temperature and sucrose solution concentration on mass transfer during osmotic dehydration process and to assess the predictive capacity of Peleg, Azuara, Magee and Rahman equations during osmotic dehydration of elephant foot yam cubes in sucrose solution.

Material and method

Osmotic dehydration of elephant foot yam cubes

Osmotic dehydration elephant foot yam (EFY) cubes having size 1 cm × 1 cm × 1 cm was done in osmotic solution of sucrose having different concentrations (40, 50, 60°Bx) and solution temperature (35, 45, 55 °C). Vegetable to solution ratio was kept 1:5 (w/w) [22] during osmotic dehydration for a regular interval of time period of (0-240 min). The temperature of the osmotic solution was maintained by hot water bath agitating@50 oscillations per minute. Agitation was given during osmosis for reducing the mass transfer resistance at the surface of the fruit and for good mixing and close temperature control in osmotic medium [23]. Stain less steel containers (of approximately 150 ml capacity) containing osmotic solution were kept in hot water bath. After attainment of desired temperature of the solution, known weight of EFY cubes was put in to the container. The EFY cubes from each container were removed at specified time and were immediately rinsed with running water to remove the solute adhered to fruit surface.

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The cubes were then spread on muslin cloth to remove the free water from the outer surface of the EFY cubes. The cubes were then put in the pre-weighed petri-dish for determination of dry matter by oven method. During experimentation, it was assumed that the amount of solid (sugars, acids, minerals, vitamins) leaching out of product into the medium was considered quantitatively negligible [24]. The water loss and solute gain were calculated as given below:

Let, initial dry matter of fresh vegetable=Z%

Initial weight of vegetable taken for osmotic dehydration= W_0 (g)

∴Initial dry matter of vegetable= $\frac{W_0 \times Z}{100} = S_0$ (say)

Let the weight of vegetable after osmotic dehydration for any time $t=W_t$ (g)

And the dry matter of vegetable after osmotic dehydration for time $t=S_t$ (g)

Then, Weight reduction, $WR=W_0 - W_t$ (g)

Solute gain after osmotic dehydration for time t , $SG=S_t - S_0$ (g)

Water Loss, $WL=WR+SG$

Water loss in g/100 g fresh sample= $\frac{WL}{W_0} \times 100$ (1)

Solute gain in g/100 g fresh sample= $\frac{SG}{W_0} \times 100$ (2)

Validation of empirical models for osmotic dehydration of EFY cubes

The validity of empirical models for water loss and solute gain during osmotic dehydration (Table 1) was checked by non linear regression technique. Azuara et al. [13] developed a model from mass balance considerations to predict the kinetics and final equilibrium point of osmotic dehydration by using data obtained during relatively short period of osmosis. In Azuara model, the constant β_1 is related to the rates of water diffusion out from the sample (min^{-1}). For solute gain instead of β_1 and WL_∞ , constant used are β_2 and, otherwise the formula used is same as that of water loss.

Adequacy of fit of empirical models

To fit the experimental data to the various empirical models, regression analysis has been carried out by statistical software STATISTICA 7.0 for windows (Statsoft, Inc Tulsa OK U.S.A.). To select the best equation various statistical parameters, such as reduced χ^2 and root mean square error (RMSE) in addition to R^2 , were also used as primary criterion [18]. For evaluating nonlinear mathematical models, these parameters are not a good criterion therefore, to select the best equation to account for variation in the drying curves of the dried samples, the percent mean relative deviation modulus ($E\%$) that indicate the deviation of the observed data from the predicted line was also used as recommended by several authors in their drying studies [25]. Therefore, the best model was chosen as one with the highest coefficient of correlation (R^2); and the least χ^2 , RMSE, and mean relative deviation modulus ($E\%$).

R^2 is a measure of the amount of variation around the mean explained by model.

$$\text{Chi Square} = \chi^2 = \sum_{i=1}^N \left[\frac{(\text{Experimental Value} - \text{predicted value})^2}{(N-n)} \right] \quad (3)$$

Where, n =no. of unknown and

N =Data point measured

$$\text{RMSE} = \text{Root mean square error} = \sum_{i=1}^N \left[\sqrt{\frac{(\text{Experimental value} - \text{predicted value})^2}{N}} \right] \quad (4)$$

The mean relative deviation $E\%$ is an absolute value that was used because it gives a clear idea of the mean divergence of the estimated data from the measured data.

$$E(\%) = \frac{100}{N} \sum_{i=1}^N \left| \frac{\text{Experimental Value} - \text{predicted value}}{\text{Experimental value}} \right| \quad (5)$$

The values of E less than 5.0 indicate an excellent fit, while values greater than 10 are indicative of a poor fit.

Results and Discussion

During the experiments on osmotic dehydration of EFY cubes an increase in water loss and solute gain has been observed with increase of osmotic solution concentration, process temperature and time. The rates of water loss and solute gain were higher in the initial stages and approached to zero in the later stages. The process variables have significant effect on the constants and exponents of the various empirical models fitted to the water loss and solute gain data obtained during osmotic dehydration. The validation of various models for water loss and solute gain during osmotic dehydration of EFY cubes has been discussed below.

Validation of Empirical Models for Water Loss

The values of statistical parameters, models constants and coefficients for water loss during osmotic dehydration are given in Tables 2 and 3. Out of the fitted models, the values of χ^2 , RMSE and $E\%$ were lower for Magee model in comparison to the Peleg model and Azuara model. There was a very good adequacy between predicted and observed data with correlation coefficient ' R^2 ' higher than 0.96 for water loss in case of Magee model. However, Azarpazhooch and Ramaswamy [26] reported that Peleg model was a best fit model for water loss in osmotic dehydration, but this model did not fit to the experimental data in the present study because of high value of $E\%$, RMSE and χ^2 .

The Azuara model (Table 3) indicates that the predicted values of equilibrium water loss were 40.231, 49.786, 59.324 g/100 g of sample at 35, 45, 55°C, respectively, for osmotic solution of 50°Bx concentration. Therefore, with increase of temperature of osmotic solution, the values of water loss at equilibrium have been increased. The predicted values of equilibrium water loss were 57.14, 59.32, 60.24 g/100 g of fresh fruit in 40, 50, 60°Bx, respectively, at 55°C of osmotic solution temperature. Therefore, with increase of concentration of osmotic solution, the values of water loss at equilibrium have been increased. The values of β_1 indicates that the rates of water loss were higher at higher concentrations and temperature in comparison to the low values of concentration and temperature may be due to the fact that increase in osmotic solution concentration increases the concentration gradient

Model Name	Model	Reference
Penetration model	$WL \text{ or } SG = K \times \sqrt{t}$	[15]
Peleg Model	$WL \text{ or } SG = K_1 + K_2 \times t$	[12]
Magee Model	$WL \text{ or } SG = A + K \times t^{1/2}$	[14]
Azuara Model	$WL_t \text{ or } SG_t = \frac{\beta_1 t (WL_\infty)}{1 + \beta_1 t} = \frac{(WL_\infty) t}{\frac{1}{\beta_1} + t}$	[13]

Table 1: Selected osmotic dehydration models.

Conc (°Bx)	Temp. (°C)	Magee model (water loss)						Peleg model (water loss)					
		A	K	R ²	χ^2	E%	RMSE	K ₁	K ₂	R ²	χ^2	E%	RMSE
40	35	3.01677	2.5059	0.97	6.1022	11.1078	2.5723	14.78721	0.12359	0.91	16.9309	18.754	4.1147
40	45	6.2810	6.3820	0.98	1.6144	4.5476	1.3710	17.78264	0.12849	0.92	6.84894	11.119	2.61704
40	55	3.7845	3.8855	0.97	4.7640	6.4143	2.2828	20.80045	0.19062	0.90	22.1364	15.7564	4.70493
50	35	2.0695	2.0795	0.99	1.3906	4.3637	1.2793	15.54508	0.15215	0.92	10.15608	13.80795	3.1868
50	45	7.7284	7.7164	0.98	4.2946	6.6693	2.0825	21.47233	0.15069	0.88	16.8150	14.25272	4.10061
50	55	4.9950	4.8960	0.98	3.1760	4.9317	1.7724	23.45795	0.21256	0.92	20.9119	13.5888	4.5729
60	35	5.5333	5.4343	0.98	3.1847	5.6983	1.7943	20.37269	0.16658	0.90	15.7033	14.25569	3.9627
60	45	8.2063	8.1073	0.97	10.135	7.9162	3.998	25.21692	0.18684	0.85	31.79	15.0833	5.6382
60	55	4.0344	4.0234	0.99	3.1039	3.8266	1.7720	23.76347	0.23316	0.94	18.20551	11.78207	4.2667

Table 2: Various regression coefficient and statistical parameters of Magee and Peleg model for water loss.

Conc (°Bx)	Temp. (°C)	WL [∞]	β_1	R ²	χ^2	E%	RMSE
40	35	37.547	0.0114	0.99	3.0124	6.6984	0.3042
40	45	46.569	0.0135	0.98	3.2567	10.254	0.38547
40	55	57.142	0.0175	0.98	4.123	8.564	0.4587
50	35	40.231	0.0186	0.99	11.256	7.987	1.2354
50	45	49.786	0.0935	0.99	17.564	10.564	0.3154
50	55	59.324	0.0212	0.99	3.654	11.256	0.9574
60	35	42.214	0.0223	0.98	19.564	13.564	0.5604
60	45	52.321	0.0243	0.99	13.254	6.354	1.2635
60	55	60.245	0.0258	0.99	26.145	8.954	1.321

Table 3: Various regression coefficient and statistical parameters of Azuara model for water loss.

and in turn the driving force for osmotic dehydration process [9] and increase in temperature decreases the viscosity of the osmotic solution, decreases the external resistance to mass transfer rate at product surface; and thus facilitate the outflow of water from cubes.

The comparative validity of the various models fitted to the water loss data can also be represented from the predicted curves of various models (Figure 1). The Figure indicates that the predicted values obtained from Magee model are very close to the experimental values.

Empirical Models for Solute Gain during Osmotic Dehydration

The solute gain during the process of osmotic dehydration at various concentrations and at various temperatures was observed at regular intervals of time. The penetration of solute goes on increasing with the passage of time and become almost constant at the end of process. There was a very good adequacy between predicted and observed data with correlation coefficient 'R²' higher than 0.96 for solute gain (Tables 4 and 5) in case of Azuara model. The values for E%, RMSE and χ^2 are less as compared to other models and value of R² is high than other models, which is the criteria used for the adequacy of good fitting of Model. Adequacy of fitting of Azuara model is in good agreement with the results found by Mundada et al., [27] in case of osmotic dehydration of pomegranate arils.

The comparison of experimental and predicted values of various osmotic dehydration models for solute gain could be analyzed visually in the Figure 2. The predicted values of solute gain given by Azuara model were very close to the experimental values for solute gain during osmotic dehydration of EFY cubes.

According to Azuara model (Table 5), predicted values of equilibrium solute gain were 9.26, 9.64, 12.86 g/100 g of fresh sample at

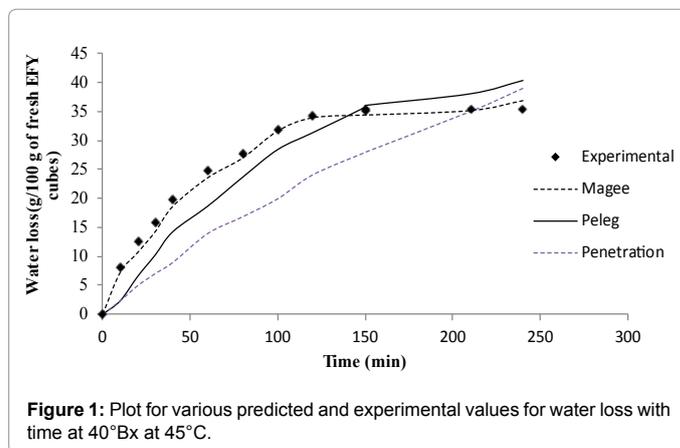


Figure 1: Plot for various predicted and experimental values for water loss with time at 40°Bx at 45°C.

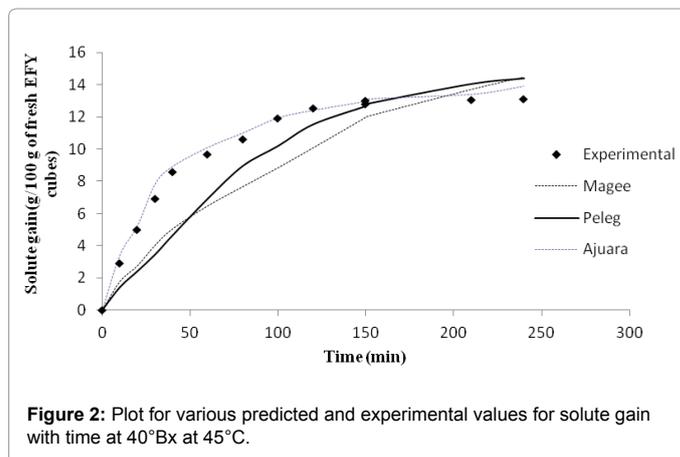


Figure 2: Plot for various predicted and experimental values for solute gain with time at 40°Bx at 45°C.

Conc.(°Bx)	Temp.(°C)	Magee model (solute gain)						Peleg model (solute gain)					
		A	K	R ²	χ^2	E%	RMSE	K ₁	K ₂	R ²	χ^2	E%	RMSE
40	35	1.6957	0.7824	0.98	0.2127	4.4275	0.3457	4.4329	0.03458	0.91	0.573	10.69	0.7573
40	45	2.9609	0.8472	0.99	0.0694	2.1855	0.2634	6.30406	0.04279	0.94	0.592	8.442	0.7695
40	55	3.5877	0.9240	0.99	0.1015	1.8886	0.3187	7.2927	0.04805	0.97	0.309	5.342	0.5559
50	35	2.2932	0.7861	0.98	0.1084	3.5912	0.3293	5.54218	0.04001	0.93	0.641	9.9769	0.8011
50	45	4.0481	0.8481	0.99	0.0529	1.9356	0.2400	7.46864	0.04399	0.97	0.282	5.4214	0.5312
50	55	4.5820	1.1402	0.99	0.1279	1.8948	0.3576	9.1689	0.05931	0.97	0.449	4.369	0.6707
60	35	2.6721	0.8614	0.99	0.0407	1.6916	0.2018	6.20413	0.04439	0.96	0.408	6.3006	0.6392
60	45	4.0604	1.0879	0.99	0.0562	1.7448	0.2573	8.4532	0.056201	0.96	0.586	5.5548	0.7656
60	55	4.6557	1.5219	0.99	0.2668	2.6868	0.5261	10.8119	0.07781	0.94	1.984	7.8928	1.4088

Table 4: Various regression coefficient and statistical parameters of Magee and Peleg model for solute gain.

Conc (°Bx)	Temp (C)	SG [∞]	β_2	R ²	χ^2	E%	RMSE
40	35	7.521	0.0348	0.98	0.0999	5.1326	0.0356
40	45	8.654	0.0254	0.99	0.0450	6.5478	0.0645
40	55	9.123	0.0088	0.98	0.0654	8.654	0.0795
50	35	9.2654	0.0045	0.99	0.0147	9.6479	0.0214
50	45	9.641	0.00145	0.99	0.1254	11.3255	0.0145
50	55	12.864	0.0013	0.99	0.3159	8.987	0.0478
60	35	10.764	0.0064	0.98	0.2647	4.679	0.0347
60	45	11.965	0.00564	0.99	0.1345	11.255	0.0614
60	55	12.954	0.00154	0.99	0.2359	8.789	0.0874

Table 5: Various regression coefficient and statistical parameters of Auara model for solute gain.

35, 45, 55°C, respectively, for osmotic solution of 50°Bx concentration. Therefore, with increase of temperature of osmotic solution, the values of solute gain at equilibrium have been increased. The values of equilibrium solute gain were 9.12, 12.86, 12.954 g/100 g of fresh sample in 40, 50, 60°Bx, respectively, at 55°C of osmotic solution temperature as predicted by Azuara model. Therefore, with increase of concentration of osmotic solution, the values of solute gain at equilibrium have been increased. The values of β_2 indicates that the rates of water loss were higher at higher concentrations and temperature in comparison to the low values of concentration and temperature. It may be due to the fact that the low concentration of sugar syrup may get diluted and reach the near saturation point quickly. An increase in osmotic solution concentration increases the concentration gradient and in turn the driving force for osmotic dehydration process and high temperature decrease the resistance due to high viscosity by lowering down the viscosity of highly concentrated solution.

Conclusion

The osmotic solution concentration, temperature and time have significant effect on water loss and solute gain during osmotic dehydration of EFY cubes. The effect of process variables on water loss and solute gain can be represented by the model constants. Among different applied equations, Magee and Auara model showed the best fitting to the experimental data for water loss and solid gain, respectively. Therefore, the osmotic dehydration process of EFY cubes can be successfully represented by appropriate models for scale up purposes.

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