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Osmotic Dehydration Kinetics of Elephant Foot Yam Cubes (*Amorphophallus Spp.*) in Sucrose Solution

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Abstract

Among tubers, Amorphophallus companulatus known as elephant foot yam is a highly potential tropical tuber crop containing a good amount of protein as well as starch, fiber, minerals and vitamins. Fresh yams are perishable in nature and deteriorate in quality on storage. The shelf life of Elephant foot yam can be increased if processed properly. The quality of the dehydrated product can be enhanced if the product is pretreated osmotically in sucrose or salt solution prior to convective dehydration. In the present study cubes of uniform size (1 cm x 1cm x 1cm) were osmotically pretreated in hypertonic sucrose solution having 45, 55 and 65 °Bx concentrations at 40, 50 and 60 °C osmotic solution temperature for different intervals of time. The sample to solution ratio was kept as 1:4. Mass transfer kinetics for water loss and solute gain were studied and the data was fitted to various empirical models (Magee, penetration and Peleg models). Out of the applied models, the Magee's model was appropriate for predicting water loss and solute gain. The highest values of water loss and solute gain were 58.8 g water/100 g of fresh sample and 25.5 g solute/100 g of fresh sample, respectively for osmotic solution having 65 °Bx. concentration and 60 °C osmotic solution temperature after 240 minutes. In first 60 minutes, water loss and solute gain were maximum i.e. 65.96% and 58.57% of total values and become almost constant after 180 minutes of osmotic dehydration. The osmotic solution concentration, temperature and time have most pronounced affect on water loss as compared to solute gain during osmotic dehydration. Both water loss and solid gain increased with increasing the concentration and temperature of osmotic agent solution.

Keywords: Osmotic dehydration; Elephant foot yam; Solute gain; Water loss.

1. Introduction

Root and tubers are the second most staple food crops after cereals which are grown throughout the world in hot and humid region (Latha et al. 2004). Yams are tuber crops having high nutritive value containing starch, minerals and vitamins. Elephant foot yam (*Amorphophallus spp.*) belongs to family Araceae is one of the major tuber crop produced in tropical and subtropical zones like india, Indonesia, Africa etc. and has great export potential since its commercial cultivation is not in many of countries (Misra et al., 2001). It is rich in nutrients like minerals (Ca, K, P and Zn), vitamins (A, B_1, B_2) and contains starch as a major energy source. Potassium is the most abundant (327.83 mg/100 g) macro mineral followed by phosphorus (166.91 mg/100 g), calcium (161.08 mg/100 g) and iron (3.43 mg/100 g) (Chattopadhyay et al, 2009). The mean soluble oxalate content (13.53 mg/100 g) of yam is safe from the viewpoint of accumulation of urinary oxalate leading to kidney stones. This tuber is consumed by many people as a food and widely used in many ayurvedic preparations (Angayarkanni et al, 2007) because it contains different bioactive components like alkaloids, flavonoids, phenols etc (Ajoy, 2010). It is an underutilized tuber crop because consumers avoid using it as regular vegetable due to some problems like itching, large size and repulsive appearance. Its transportation and storage is also difficult because of its large size and perishable nature (due to high moisture content of 75-80% wet basis). There is a great need to increase its shelf life, which can be possible by using dehydration whose basic objective is the removal of water from the raw materials to extend the shelf life by reducing the water activity of food products (Phisut, 2012). Osmotic dehydration is used to improve the economics of dehydration processes for extension of the sustainability of fruit and vegetable drying. The osmotic dehydration process is a partial removal of water from food material to obtain a better quality final product. These osmodehydrated fruits and vegetables can be directly used in human nutrition or as an intermediate material for further drying and these products can be used as components of cereals or snacks (Singh & Wadhwa, 2012). Among vegetables, some of the good examples of osmotic dehydration are tomato, potato, pumpkin, carrot and onions (Le Maguer 1988, Singh & Wadhwa, 2012). The quality traits and nutritional value of osmodried fruits and vegetables can be modified by processing parameters like temperature and concentration of osmotic solution, time duration of process and type of osmotic agent etc. used during osmotic dehydration (Chiralt and Talens, 2005). Advantages of this process is quality improvement, higher retention of initial food characteristics due to less heat used (Beaudry 2001), packaging and distribution cost reduction, product stability during storage, no chemical requirement, shortening of the drying process resulting lower energy requirements (Lenart and Lewicki, 1988). So, osmotic dehydration can be a useful technique for increasing the utilization of this underutilized tuber by preserving and obtaining new processed products of interest to the consumer. Keeping in view the aspects, the present work was aimed to study the osmotic dehydration kinetics of elephant foot yam cubes in osmolytic solution (sucrose) and to evaluate the adequacy of different empirical models to predict the water loss and solute gain during osmotic dehydration.

2. Materials & Methods

Experiments were conducted to study the effect of osmotic solution concentration (45, 55, 65 °Bx), temperature (40, 50, 60 °C) and immersion time (0-240 min) on water loss and solid gain during osmotic dehydration process of elephant foot yam cubes of uniform size (1cm x 1 cm x 1cm). For each experiment, the ratio of osmotic solution to sample was kept as 4:1 (Lenart and Flink, 1984). The temperature of the osmotic solution was maintained by hot water bath agitating at the rate of 50 oscillations/minutes. Prior to osmotic dehydration blanching of cubes was done in hot boiling water for 1-2 minutes to inactivate enzymes.

2.1 Mass Transfer Parameters

The water loss and solid gain were estimated by using following expressions (Hawkes and Flink, 1978; Singh et al, 2007):

$$\text{Water loss in g/100 g of sample} = \frac{WL}{W_0} \times 100 \tag{1}$$

$$\text{Solute gain in g/100g sample} = \frac{SG}{W_0} \times 100 \tag{2}$$

$$\text{Initial dry matter of sample taken} = \frac{W_0 \times Z}{100} = S_0 \tag{3}$$

Where, water Loss (WL) = WR + SG; Weight Reduction (WR) = $W_o - W_t$ (g); Solute gain (SG) after OD for time t = $S_t - S_o$ (g); Initial wt. of sample taken for OD = W_o (g); Wt. of sample after OD for any time t = W_t (g); Dry matter of sample after OD for time t = S_t (g), Initial dry matter of fresh sample= Z %

2.2 Kinetic Models For Osmotic Dehydration

Mass transfer kinetics during osmotic dehydration was modeled according to Magee's model, penetration model and peleg model, which establishes a relation between kinetic variables such as water loss (WL) and solute gain (SG) with immersion time.

Penetration model	WL or SG = $K^* \sqrt{t}$	Rahaman (1992)
Peleg Model	WL or SG = $K_1 + K_2 {}^* t$	Peleg (1988)
Magee Model	WL or SG = $A + K\sqrt{t}$	Magee et al. (1983)

The models adequacy for the best fitting of experimental data was evaluated by obtaining the coefficient of correlation (R^2) and least RMSE, χ^2 and percent mean relative deviation of modulus (E%) using following equations:

$$E(\%)=\frac{100}{N}\sum_{i=1}^{N}\left|\frac{Experimental\,Value-predicted\,value}{Experimental\,value}\right| \tag{4}$$

$$Chi\;\;Square=\chi^{2}=\sum_{i=1}^{N}\left[\frac{(Experimental\;\;Value-predicted\;\;\;value)^{2}}{(N-n)}\right] \tag{5}$$

$$RMSE=Root\,mean\,square\,error=\sum_{i=1}^{N}\left[\sqrt{\frac{(Experimental\;\;value-predicted\,value)^{2}}{N}}\right] \tag{6}$$

Where, n = no. of unknown and N= no. of observations. The nonlinear regression analysis was performed by using Statsoft Statistica version 7.0.61.0 EN.

3. Result and Discussion

3.1 Effect of Osmotic Solution Concentration and Immersion Time on Mass Transfer Kinetics

Water loss as well as solute gain in elephant foot yam cubes during osmotic dehydration increased non-linearly with time at all concentrations and temperatures. The slopes of the water loss and solute gain curves in Fig.1 indicate that there is rapid water loss and solute gain rates in the initial stages of osmosis and then the rate decreased in the later stages**.** The total water loss and solute gain values were 52.4 g water/100 g fresh sample and 21.9 g solute/100 g fresh sample, respectively in 65 °Bx at 40 °C. In the first hour of osmotic dehydration process the values of water loss and solute gain were 34.5 g water/100 g fresh sample and 15.8 g solute/100 g fresh sample, respectively. It was observed that 65.96% water loss of total value of water loss and in the same way 58.57% of solute gain of total value of solute gain took place in the first hour of the process and in the last three hours only 34.04% water loss and 41.43% solute gain took place. During the initial 60 minutes of osmotic dehydration process the average water loss and solute gain rates were 0.58 (g water/100 g fresh sample)/ minute and 0.25 (g solute/100 g fresh sample)/minute and in the later stages the rate decreased to 0.10 (g water/100 g fresh sample)/ minute and 0.04 (g solute/100 g fresh sample)/ minute. This may be due to the largest difference in osmotic pressure between the osmotic solution and cell sap of the material and small mass transfer resistance initially and decrease in osmotic driving potentials due to migration of water from sample to solution and solute from solution to sample which will result in decrease of water and solute transfer in later stage (Shukla et al, 2012). Another reasons are progressive solid uptake during osmotic dehydration resulted in the formation of high solids subsurface layer on the external cellular layer of cubes, which interfered with the concentration gradient across the product solution interface and acted as a barrier against removal of water and uptake of solids (Hawkes and Flink, 1978) and may be due to the rapid loss of water and solute gain from the surface in the initial stages of process may result into structural changes leading to compaction of outer surface layers and increased resistance to mass transfer (Sutar and Gupta, 2004). Similar results were also reported for osmotic dehydration of banana slices (Shukla et al, 2012), onion slices (Alam et al, 2013) and carrot cubes (Singh et al, 2007). Conway et al, 1983 reported that mass transport data were not significantly changed in the period between 4 h to 20 h. Therefore, it is suggested that osmotic dehydration should be done not more than four hours (Kulwinder Kaur and A. K. Singh, 2013).

The increase in water loss and solute gain was observed with increase of osmotic solution concentration at all temperature. Elephant foot yam cubes immersed into a 65 °Bx sucrose solution showed a higher water loss and solute gain compared to those immersed in 55 °Bx and 45 °Bx osmotic solutions (Fig.1.1 and 1.2). Graphs were plotted only at 40 °C because same trend was followed by other temperatures i.e. 50 and 60 °C. The highest water loss and solid gain (52.44 g water/100 g fresh sample and 21.98 g solute/100 g fresh sample) are given by 65 °Bx sucrose solution and is closely followed by 55 °Bx sucrose solution (48.7 g water/100 g fresh sample and 20.234 g solute/100 g fresh sample), while the lowest (43.67 g water/100 g fresh sample and 18.52 g solute/100 g fresh sample) are given by 45 °Bx sucrose solution even as low temperature (40 °C) for the 240 minutes osmosis period. Alam et al, 2013 also reported in summer onion that water loss and solute gain increases with increased concentration of osmotic solution. In osmotic solution of 65 °Bx at 40 °C total water loss and solute gain values were 34.52 g water/100 g fresh sample and 15.8 g solute/100 g fresh sample whereas in the solutions of 45°Bx the water loss and solute gain values were 26.94 g water/100 g fresh sample and 10.85 g solute/100 g fresh sample, respectively in the first 60 minutes of the process. At high concentration 65 °Bx water loss and solute gain values were 3.57 g water/100 g fresh sample and 1.65 g solute/100 g fresh sample whereas at low concentration i.e. at 45°Bx, in the last 60 minutes of the process water loss is only 1.38 g water/100 g fresh sample and solute gain is 0.72 g solute/100 g fresh sample of the total values of water loss and solute gain. It was observed from the data that water loss and solute gain values were higher at higher concentration of osmotic solution and initial time of immersion but at low concentration in the later stages of the process water loss and solute gain values were much lower than the values in the initial stage. 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 (Rastogi and Raghavarao, 2004).

The effect of concentration was more pronounced on water loss than the solute gain. This behavior is in agreement with (Falade, 2003). The values of solute gain were much lower (25.5 g solute/100 g fresh sample) than the values of water loss (58.8 g water/100 g fresh sample) in 65 °Bx at 60 °C during osmotic dehydration, this may be due to higher molecular weight of sucrose (342 g) than Water (18g). The similar behavior of osmotic solution concentration for water loss and solute gain values were found in 45 and 55 °Bx at 40 and 50 °C process temperatures, respectively. Similar results were also reported by Antonio et al, 2008 in case of sweet potato**.** As the concentration of the osmotic solution increases the rate of water removal also increases (Shukla et al., 2012). Low osmotic solution concentration implies a lower process driving force and subsequently longer treatment time *(Agarrya & Owaborb, 2012).*

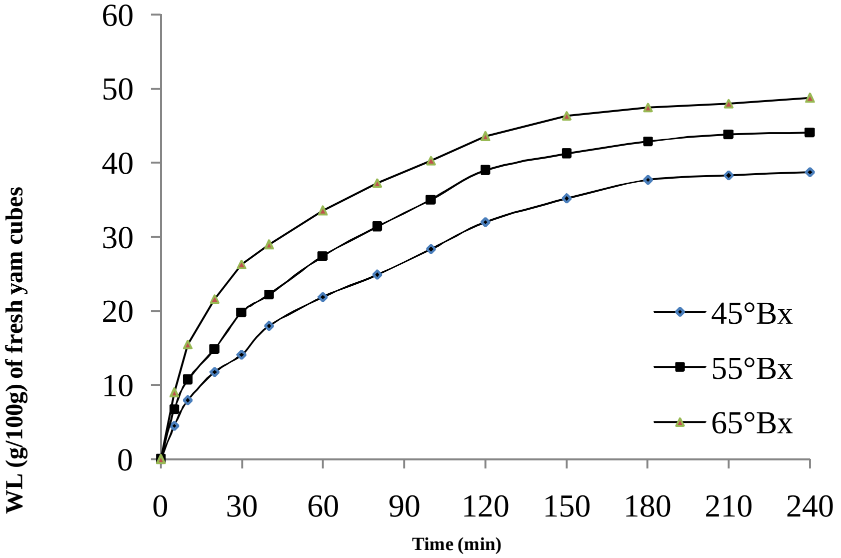


Fig. 1.1

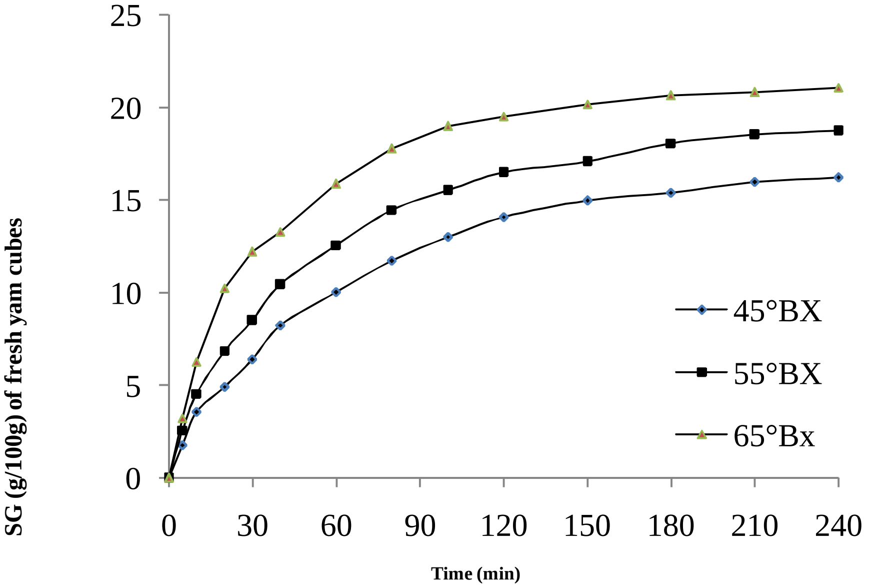
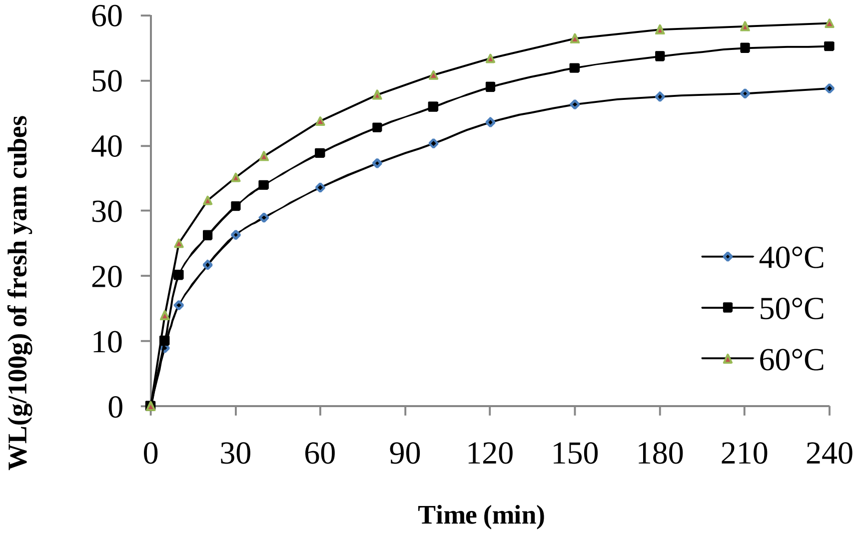


Fig.1.2



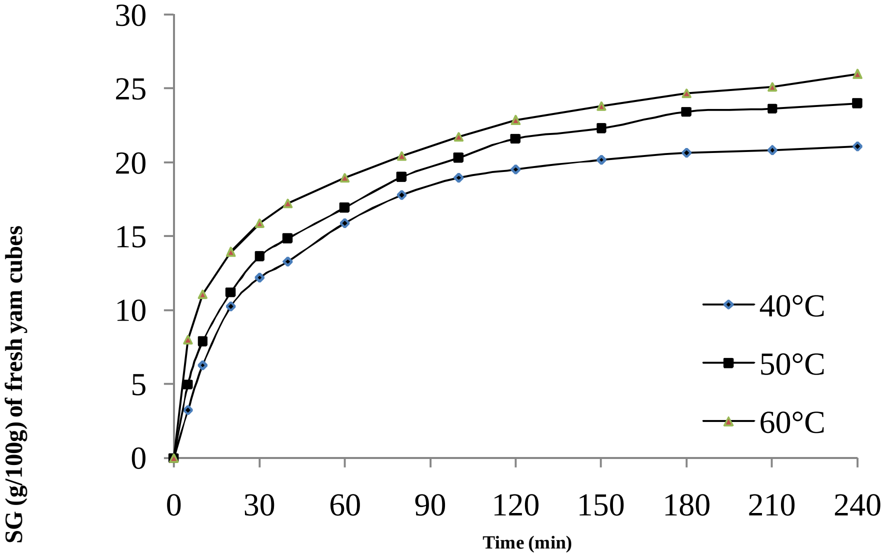


Fig.1.4

Figure 1: Effect of osmotic solution concentration and immersion time at 40 °C (Fig. 1.1 and 1.2) and osmotic solution temperature and immersion time in 65 °Bx concentration (Fig. 1.3 and 1.4) on water loss and solute gain respectively during osmotic dehydration of elephant foot yam cubes in sucrose solution.

3.2 Effect of osmotic solution temperature on mass transfer kinetics

Fig.1.3 and 1.4 indicate an increase in water loss and solute gain with increase in osmotic solution temperatures respectively. Higher water loss and solute gain were observed at 60 °C compared to those at 50 °C and 40 °C temperature. The results show that maximum water loss at 60 °C (58.85 g water/100 g fresh sample) followed by 50 °C (55.2 g water/100 g fresh sample) while minimum was observed for 40 °C (52.4 g water/100 g fresh sample) when other parameters like concentration (65 °Bx) and time (240 minutes) were same. Similarly solid gain was also increased with increasing temperature i.e. 21.9, 23.8, 25.5 g solute/100 g fresh sample at 40, 50 and 60 °C. This might be due to reason that increase in temperature decreases the viscosity of the osmotic solution, decreases the external resistance to mass transfer rate at product suface; and thus facilitate the outflow of water from cubes and diffusion rates of solute into the cubes. Higher temperature facilitates swelling and plasticizing of cell membranes and thus would release trapped air from the tissue (Uddin et al, 2004) resulting in more effective removal of water by osmotic pressure. Another reason is that increase in temperature increases the surface heat transfer coefficient, which influences the heat and mass transfer rate. Wray and Ramaswamy, 2013 also reported that water loss and solute gain increases with increase in temperature of an osmotic solution in case of cranberries.

3.3 Validation of empirical models for water loss and solute gain

The validity of Magee, Peleg and penetration models were checked for predicted water loss and solute gain. In all the experiments of osmotic dehydration, solutions having different concentration and temperatures, the models having lower values of R^2 and high values of root mean square error (RMSE), mean standard deviation modulus (E%) and Chi square (χ^2) were rejected and vice versa. It was observed that Magee model was the best fitted model as compared to other models for water loss because there was a very good adequacy between predicted and observed data with correlation coefficient R^2 higher than 0.97 for water loss in case of Magee model. This fact also confirmed that the model equation is a good representation of the process and so can be used for process development purposes (Manivannan and Rajasimman, 2008). In Magee model the values for E%, RMSE and are 2.087, 2.9723 and 6.18 are respectively, which are less as compared to other models values and value of R^2 is higher than other models which is the criteria used for the adequacy of good fitting of Model. However, Mundada et al, 2011 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. 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. Magee model fit appropriately for solute gain because of higher R^2 (>0.96) but there was not a good adequacy between predicted and observed data with applied models because of the higher values of E%, RMSE and for solute gain. However, Pokharkar and Prasad, 1998 reported that Penetration model was a universal model for 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.

4. Conclusion

It can be concluded from this study that solution concentration, time and temperature were the most pronounced factors affecting water loss and solute gain of elephant foot yam cubes during osmotic dehydration. Both water loss and solute gain both were higher in first hour of osmotic dehydration than last hour at all concentration and temperatures. Both water loss and solute gain were highest in 65 °Bx at 60 °C. Magee model was the appropriate model out of the applied models for present study. By processing elephant foot yam, its post-harvest losses can be minimized, its market value and utilization can be increased and production can be maximized. Further research is needed to optimize process variables for high quality acceptable products produced for export market.

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