Mass Transfer Kinetics of Osmotic Dehydration of Beetroot Cubes in Sucrose Solution

Bhupinder Singh
CDL State Institute Of
Engineering and Technology,
Panniwala Mota (Sirsa),Haryana

Bahadur Singh Hathan
Sant Longowal Institute Of
Engineering and Technology,
Longowal (Sangrur),Punjab

ABSTRACT
Osmotic dehydration kinetics of beetroot cubes in sucrose solution having different concentrations (30°Brix, 45°Brix and 60°Brix), solution temperature 35, 45 and 55 °C, sample to solution ratio 1:4 were studied up to 240 min duration. For osmotic dehydration of beetroot in solution of sucrose the effect of all process parameter were significant at 5% level of significance on both water loss and solute gain ($p<0.05$). The magnitude of β-values revealed that osmotic solution concentration, temperature and time have positive effect on water loss and solute gain during osmotic dehydration. In case of solute gain, concentration has least effect as compared to temperature of osmotic solution and time of osmotic process. Among the different models applied (Peleg Model ,Penetration Model, Power Law Model, Magee Model, Azuara Model), Power Law Model best fitted to the experimental data for water loss and solute gain during osmotic dehydration.

Keywords
Beetroot, modelling, osmotic, mass transfer

1. INTRODUCTION
Fruits and vegetables are considered as good source of vitamins and minerals, their consumption in well planned manner may prevent many serious diseases like heart attack, obesity, cancer etc. [1]. India is the second largest producer of fruits after China, with a production of 68466 thousand metric tons of fruits from an area of 6101 thousand metric hectares [2]. Beet-root (Beta vulgarius) has various varieties from yellow to red and due to its antioxident properties effective against cancer [3]. Although it is directly consumed fresh in form of salad as well as juice and its use as candies is particularly promising in creating functional food products. However, owing to its seasonal character and perishable nature, huge amount of beetroot are wasted due to inadequate mishandling and storage practices. Osmotic dehydration is the method in which the partial removal of water from plant tissues takes place by immersing them in a hyper-tonic solution which results in an increase of the water loss and may be used as ready-to-eat, or just as a pre-processing to drying, freezing, pasteurization, and canning ([4]-[5]). In recent years, the main emphasis has been focused on osmotic dehydration as a preservation technique for fruits and vegetable to keep sensory and nutritional properties similar to fresh fruits and vegetables [6] Freeze drying is an eminent and expensive method of food preservation with reference to good quality. Accordingly, there is a prerequisite for a techno-financial exchange process, which has low capital speculation, offers a way to save highly perishable products and make them available for the regions away from production zones and thus osmotic dehydration is one of the alternative [7]. Majority of the published studies have investigated that convective drying in hot air is the most popular method applied to reduce the moisture content of fruits and vegetables, including beetroot ([8]-[10]). However, this method takes long time and high temperatures for drying that have effects on nutritive value of products. The purpose of the present work was to study of osmotic dehydration kinetics of beetroot in sucrose solution having different concentrations and temperatures with fixed sample to solution ratio.

2. MATERIALS AND METHODS
2.1 Preparation of sample
Fresh beetroot were collected from native market of Sirsa, Haryana (India) on consistent schedule before every arrangement of test. They completely washed with water to remove soil and other fragments. At that point, they were cut into blocks (1cm ×1cm×1cm) utilizing clean blade. No blanching was done before diffusion because it is damaging to the diffusion dehydration method because of loss of semi-permeability of cell membranes [11]. Sugar, the osmotic agent, was bought from a nearby market. The osmotic solution is prepared by mixing the sugar with adequate amount of distilled water.

2.2 Osmotic dehydration of Beetroot Cubes
For osmotic dehydration process stainless steel containers were placed in placed in a thermostatically controlled water bath along with shaker. Beetroot cubes were properly weighed and put up into stainless steel containers filled with osmotic solution of different concentrations. Osmotic solution temperature was properly maintained in hot water bath agitating at the rate of 50 oscillations per min. Fresh osmotic solution was used to conduct all experiments. All the experiments were done in triplicate and the average value was taken for calculations.

Agitation was given throughout diffusion for reducing the mass transfer resistance at the surface of the fruit and for proper blending and close temperature management in diffusion medium [29]. The beetroot cubes were expelled from the holder at the predefined time and flushed with crisp water to evacuate the overabundance solute stuck to the surface. The osmotically dried out beetroot solid shapes were then spread on a permeable paper to expel the free water present on the external surface.

Then out of the total osmotically dehydrated beetroot, about 15–20 g sample was put in the pre-weighed petri dish for determination of dry matter by oven method .The remaining part of the sample was dried to final moisture content of 10% (wet basis) in hot air dryer at 60 °C air temperature.

2.3 Calculation of water loss and solute gain during osmotic dehydration process

The water loss and solute gain during osmotic dehydration were calculated by the equations given by [12] given as below:

Let initial dry matter of fresh fruit = Z %

Initial weight of fruit taken for osmotic dehydration = W0 (g)

$$\therefore \text{Initial dry matter of fruit} = \frac{W_o * Z}{100} = S_o$$

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

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

Then

Weight Reduction =WR = $W_o - W_t$ (g)

Solute Gain after osmotic dehydration for time t = SG= $S_t - S_o$ (g)

Water Loss = WL =WR + SG

$$\text{Water loss in g/100 g Fresh Fruit} = \frac{WL}{W_o} * 100$$

$$\text{Solute gain in g/100g Fresh Fruit} = \frac{SG}{W_o} * 100$$

2.4 Validation of empirical models for osmotic dehydration of beetroot

The validity of following empirical models (Table 2) was checked by non-linear regression technique to predict the kinetics of moisture ratio and solute gain ratio of osmotic dehydration process. Whereas Power, Penetration and Magee models are based on the idea, that concentration changes only near the surface of the sample [13].

2.5 Statistical analysis

The linear regression analysis of the experimental data was carried out to observe the significance effect of various process parameters on the water loss and solute gain during osmotic dehydration by the software statistica 7(India). The relative effect of each process parameter was compared from the β values corresponding to that parameter. The β coefficients were regression coefficient obtained by first standardizing the process variables to mean zero and standard deviation to one. Thus, advantage of using β-coefficient as compared B- coefficients (which are not standardized) was that magnitudes of these values allow us to compare the relative contribution of every independent variable for the prediction of dependant variable using statistica 7(India). Higher the positive value of β of a parameter shows more effect of that parameter. The negative values of β indicate the negative effect of that parameter. The magnitude of significance of various process parameters on water loss and solute gain during osmotic dehydration of beetroot in sucrose solution is give in table 1.

2.6 Adequacy of fit for empirical models

In addition to R^2, reduced chi-square (χ^2) and root-mean-square error (RMSE) are not a good criterion for evaluating non-linear mathematical models,therefore,the percent mean relative deviation modulus (E%) was also used to select the best equation (Azoubel & Murr,2004) that indicate the deviation of the observed data from the predicted line.the model that represents highest coefficient of correlation (R^2) was chosen as one with the highest coefficient of correlation and the least χ^2 , RMSE and mean relative deviation modulus (E) less than 5.0 indicate an excellent fit.

3. RESULT AND DISCUSSION

The individual effects of various process parameters on kinetics of water loss and solute gain during osmotic dehydration of beetroot is discussed below:

3.1 Mass transfer kinetics of beetroot during osmotic dehydration

To study the kinetics of water loss and solute gain during osmotic dehydration process, the experiments were conducted according to full factorial design with 3 factors viz. osmotic solution concentration (35, 45, 60°Bx), osmotic solution temperature (35, 45, 55°C) and immersion time (0 to 240 min) was used. The fruit to solution ratio was kept 1:4 (w/w) during all the experiments. The temperature of the osmotic solution was maintained by hot water bath agitating @ 50 oscillations per minute.

3.2 Effect of various process parameters on osmotic dehydration kinetics

Table 1 indicates that during osmotic dehydration of beetroot in solution of sucrose the effect of all process parameter were significant at 5% level of significance on both water loss and solute gain ($p<0.05$). The magnitude of β- values revealed that osmotic solution concentration, temperature and time have positive effect on water loss and solute gain during osmotic dehydration. The osmotic dehydration process time has more contribution to water loss (β = 0.8489) followed by osmotic solution concentration (β = 0.3789) and temperature (β = 0.3187). Similarly, for solute gain during osmotic dehydration, the maximum effect was of time (β = 0.8367) followed by osmotic solution temperature (β = 0.3975) and concentration (β = 0.2416). In case of solute gain, concentration has least effect as compared to temperature of osmotic solution and time of osmotic process, which is in close agreement with the results of [29].

3.3 Effect of Immersion time and osmotic solution concentration on water loss and solute gain

The amount of water loss and solute gain in beetroot during osmotic dehydration increased with increase of immersion time at all process conditions. The slopes of the water loss and solute gain curves (i.e. rates) in Figure 1 and Figure 2 indicates 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 decrease in water loss and solute uptake rates in the later period might be due to reason that with the progression of time, the water will migrate from sample to solution and solute from solution to sample which will result in decrease of concentration gradient between solution and fruit (ie. the osmotic driving potentials for moisture and solute transfer). Similar results were also reported by [15] for osmotic dehydration of carrot cubes. As reported by [17] that progressive solid uptake during osmotic dehydration might have resulted in the formation of high solids subsurface layer on outer layer of beetroot, which interfered with the concentration gradient across the product- solution interface and went about as an obstruction against expulsion of water and uptake of solids [16].

The increase in water loss and solute gain was also observed with increase of osmotic solution concentration (Figure 1 and 2). Beetroot immersed into 60°Bx sucrose solution showed higher water loss and solute gain compared to those immersed in 45°Bx and 30°Bx osmotic solutions. This might be due to increase in osmotic driving force potential between the beetroot and the surrounding sucrose solution. An increase in osmotic solution concentration increases the concentration gradient ([17]-[18]) and in turn the driving force for osmotic dehydration process. The similar behavior osmotic solution concentration water loss and solute gain values found at 35°C and 45°C process temperature.The Figure 3 also shows that solute gain was negligible as compared to water loss in beetroot. This might be due to high molecular weight of sucrose favors the water loss as compared to solute gain [5].

3.4 Effect of osmotic solution temperature on water loss and solute gain

Figures 4 and Figure 5 indicate an increase in water loss and solute gain with increase in osmotic solution temperature. Higher water loss and solute gain were observed at 55°C compared to those at 45°C and 35°C. This might be due to reason that increase in temperature decreases the viscosity of the osmotic solution, decreases the external resistance to mass tranfer rate at product suface; and thus facillate the outflow of water from beetroot and in high diffusion rates of solute into the beetroot.Water loss and solute gain increases with increase in temperature of an osmotic solution reported by ([19]-[20]).Similar behaviour of water loss and solute gain were observed during osmotic dehydration of beetroot at 30°Bx and 45°Bx. The increase in water loss and solute gain with time, temperature and concentration may also be due to agitation given during osmotic dehydration process which reduces the mass transfer resistance between the surface of beetroot and osmotic solution ([21],[28]).

3.5 Validation of empirical models for osmotic dehydration of beetroot cubes

Among all the empirical models for osmotic dehydration , Penetration model showed the lower value of R^2.Tables 3–7 indicate that, Power law model and Peleg model represented the experimental data of osmotic dehydration with more accuracy. Further, for water loss and solute gain power law model had an excellent fit as compared to peleg model due to lower values of E(%). Similar results were reported by ([22]-[23]). However,it was also reported that Penetration model was a universal model [24] for osmotic dehydration, but this model did not fit to the experimental data in the present study.

4. CONCLUSIONS

Osmotic dehydration kinetics of beetroot cubes in sucrose solution having different concentrations (30°Brix, 45°Brix and 60°Brix), solution temperature 35, 45 and 55 °C, sample to solution ratio 1:4 were well represented by different models. However, Power Law Model was found to be fitted best as this model could predict the values of equilibrium moisture content and equilibrium solid content without conducting the experiments for long duration. The magnitude of β- values revealed that osmotic solution concentration, temperature and time have positive effect on water loss and solute gain during osmotic dehydration. In case of solute gain, concentration has least effect as compared to temperature of osmotic solution and time of osmotic process.

Table 1. Regression summary for dependant variable water loss and solute gain for osmotic dehydration of beetroot

	Water loss			**Solute gain**		
	R^2 = 0.9225			R^2= 0.8974		
	β	B	p- level	β	B	p- level
Intercept	-	-5.4881	< 0.0001**	-	-8.20291	< 0.0001**
Time	0.8489	0.1798	< 0.0001**	0.8367	0.031174	< 0.0001**
Concentration	0.3789	0.6908	< 0.0001**	0.2416	0.06756	< 0.0001**

Table 2. Selected osmotic dehydration models

Model Name	**Model**	**Reference**
Power law model	WL or SG= $(K*t^N)$	[13]
Penetration model	WL or SG = $K*\sqrt{t}$	[13]
Peleg Model	WL or SG = $K_1 + K_2*t$	[25]
Magee Model	WL or SG = $A + K*t^{1/2}$	[26]
Azuara Model	WL or SG = $(WL_\infty*t*\beta)/(1 + \beta*t)$	([27],[19])

Table 3. Various regression coefficient and statistical parameters of Peleg model

Conc	Temp.	Water loss						Solute gain					
		K_1	K_2	R^2	χ^2	RMSE	E%	K_1	K_2	R^2	χ^2	RMSE	E%
30	35	0.894	0.0219	0.97	8.315	2.579	9.53	2.631	0.209	0.97	0.0716	0.239	5.478
30	45	0.771	0.0192	0.97	9.38	2.987	8.87	3.671	0.172	0.95	0.159	0.307	7.67
30	55	0.6322	0.0183	0.97	9.24	2.719	7.15	5.296	0.108	0.94	0.601	0.6393	13.45
45	35	0.685	0.0208	0.97	8.871	2.663	8.423	4.5971	0.145	0.94	0.346	0.526	11.025
45	45	0.674	0.0165	0.97	13.924	3.339	9.614	4.042	0.141	0.93	0.401	0.566	11.29
45	55	0.503	0.016	0.96	16.276	3.608	8.725	4.43	0.098	0.94	0.59	0.687	12.2
60	35	0.641	0.0156	0.97	11.061	2.974	7.928	5.105	0.1187	0.93	0.549	0.662	12.64
60	45	0.524	0.0141	0.97	18.03	3.598	8.86	4.324	0.104	0.91	0.901	0.987	14.96
60	55	0.35095	0.0139	0.97	19.211	3.92	7.196	3.245	0.0989	0.97	0.5512	0.664	10.09

Table 4. Various regression coefficient and statistical parameters of Penetration model

Conc.	Temp	Water loss					Solute gain				
		K	R^2	χ^2	RMSE	E%	K	R^2	χ^2	RMSE	E%
30	35	0.424	0.269	104.42	9.134	37.109	0.0534	0	3.37	1.642	42.69
30	45	0.489	0.244	138.89	10.541	37.144	0.0611	0	3.254	1.614	40.179
30	55	0.529	0	183.309	12.109	38.346	0.0831	0.478	3.477	1.6667	34.883
45	35	0.472	0	146.069	10.809	38.046	0.0682	0	3.0528	1.562	37.299
45	45	0.568	0.291	183.79	12.125	36.778	0.0721	0	3.572	1.691	37.231
45	55	0.616	0	259.545	14.401	38.282	0.0941	0.43	4.623	1.9231	35.645
60	35	0.598	0.228	212.251	13.037	37.678	0.0784	0.362	3.291	1.623	35.446
60	45	0.678	0	282.549	15.032	37.691	0.09	0.356	4.372	1.871	34.512
60	55	0.734	0	432.289	18.597	39.776	0.099	0	6.483	2.278	37.458

Table 5. Various regression coefficient and statistical parameters of Power law model

Conc	Temp.	Water loss						Solute gain					
		K	N	R2	χ^2	RMSE	E%	K	N	R2	χ^2	RMSE	E%
30	35	5.518	0.3687	0.99	0.634	0.711	2.25	1.561	0.206	0.99	0.008	0.0491	1.015
30	45	7.75	0.367	0.99	0.64	0.715	2.267	1.251	0.277	0.99	0.021	0.131	2.251
30	55	7.768	0.343	0.99	0.247	0.4254	1.267	0.959	0.391	0.99	0.129	0.322	5.856
45	35	7.0597	0.339	0.99	0.496	0.63	1.688	1.0573	0.332	0.99	0.051	0.201	4.146
45	45	7.27	0.371	0.99	0.998	0.893	1.989	1.172	0.323	0.99	0.0765	0.248	4.987
45	55	9.64	0.33	0.99	0.967	0.881	1.986	1.117	0.384	0.99	0.107	0.292	4.879

60	35	7.75	0.367	0.99	1.254	0.948	1.841	0.9796	0.389	0.98	0.108	0.294	5.561
60	45	9.345	0.356	0.99	1.414	0.9558	1.871	1.134	0.378	0.98	0.239	0.437	7.74
60	55	13.68	0.297	0.99	0.518	0.645	1.276	1.499	0.338	0.99	0.0748	0.244	1.499

Table 6. Various regression coefficient and statistical parameters of Magee model

Conc.	**Temp**	**Water loss**						**Solute gain**					
		A	**K**	R^2	χ^2	**RMSE**	**E%**	**A**	**K**	R^2	χ^2	**RMSE**	**E%**
30	35	15.60900	0.23919	0.98	3.689	1.718	13.725	2.833	0.0189	0.97	0.0523	0.204	1.328
30	45	17.931	0.272	0.98	5.956	2.182	20.348	2.767	0.0277	0.99	0.86	0.263	2.14
30	55	20.603	0.281	0.98	7.814	2.501	22.691	2.881	0.0484	0.99	0.047	0.1953	0.683
45	35	18.473	0.248	0.98	4.981	1.996	18.147	2.706	0.039	0.99	0.02725	0.1477	0.531
45	45	20.667	0.319	0.98	7.185	2.391	22.208	2.919	0.0368	0.99	0.0485	0.196	0.948
45	55	24.663	0.319	0.98	8.067	2.54	20.3	3.294	0.0539	0.98	0.135	0,329	1.963
60	35	21.956	0.3301	0.98	12.784	3.197	30.58	2.814	0.044	0.99	0.014	0.107	0.2437
60	45	25.59	0.371	0.99	11.78	3.07	28.651	3.237	0.0511	0.99	0.0389	0.1764	0.715
60	55	31.8	0.34	0.97	12.609	31.176	24.439	3.294	0.053	0.98	0.135	0.329	1.96

Table 7. Various regression coefficient and statistical parameters of Azuara model

Conc.	**Temp.**	**Water loss**						**Solute gain**					
		WL∞	γ_1	R^2	χ^2	**RMSE**	**E%**	**SG∞**	γ_2	R^2	χ^2	**RMSE**	**E%**
30	35	47.619	0.00198	0.94	9.174	2.7	10.79	5.102	0.754	0.99	1.896	1.231	32.29
30	45	55.55	0.0146	0.98	24,883	4	15.423	6.25	0.761	0.986	5	2	51.06
30	55	58.825	0.0116	0.98	82.104	8.104	26.555	9.523	0.5726	0.96	19.289	3.928	84.56
45	35	52.13	0.0146	0.98	18.241	5.144	18.24	7.74	0.743	0.97	9.598	2.771	67.58
45	45	66.66	0.0106	0.98	76.81	7.83	24.459	7.76	0.653	0.97	9.81	2.8	63.9
45	55	66.66	0.0085	0.98	259.905	14.41	38.76	10.638	0.434	0.96	21.84	4.181	80.2
60	35	66.66	0.0097	0.98	144.95	10.769	31.41	8.928	0.62	0.96	16.3	3.612	80.53
60	45	76.923	0.0073	0.98	333.428	16.33	40.528	10.64	0.434	0.96	21.84	4.178	80.19
60	55	76.923	0.0054	0.98	838.46	25.891	54.927	10.752	0.344	0.95	16.51	3.63	61.921

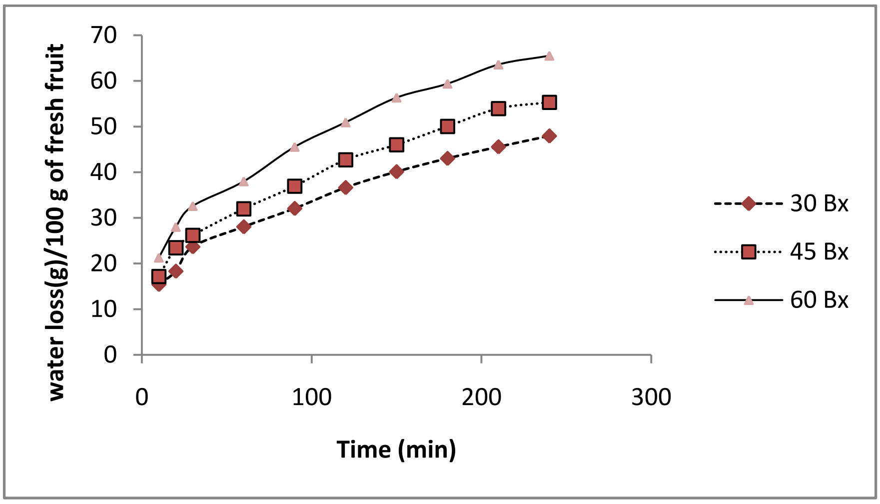

Fig 1: Effect of osmotic solution concentration and time on water loss at 45°C.

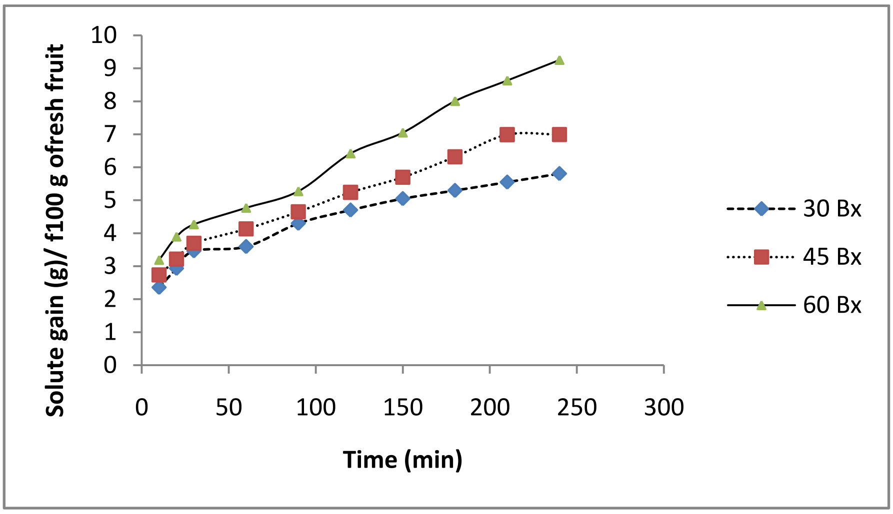

Fig 2: Effect of osmotic solution concentration and time on solute gain at 45°C.

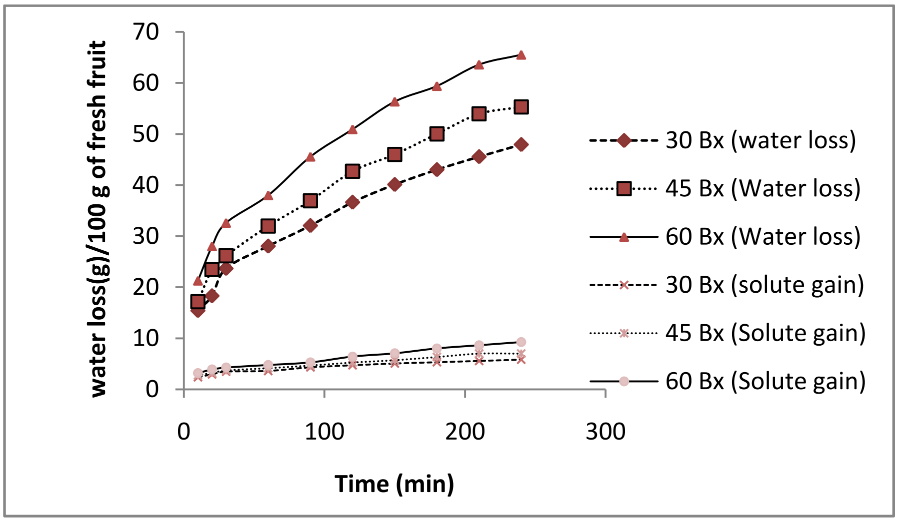

Fig 3: Effect of osmotic solution concentration and time on water loss and solute gain at 45 °C.

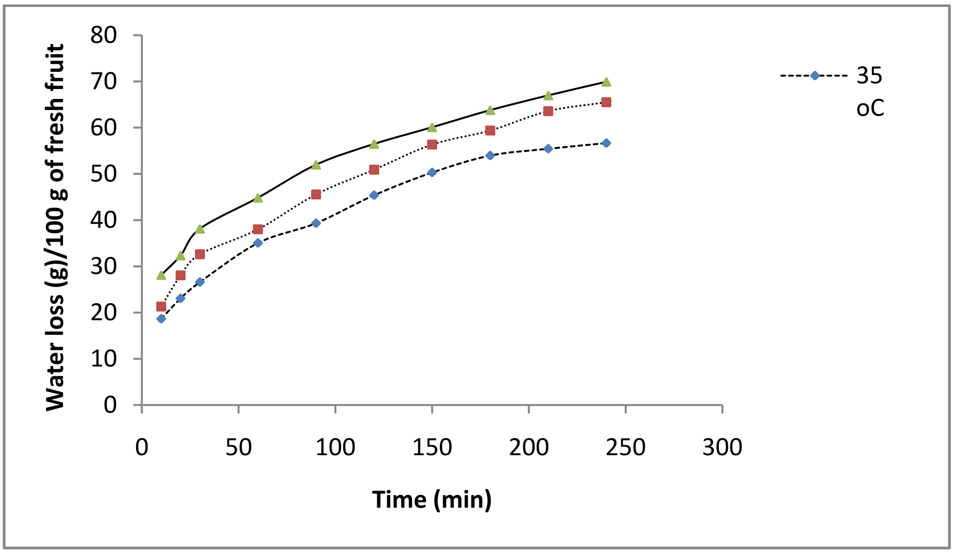

Fig 4: Effect of osmotic solution temperature and time on water loss at 60 °Bx.

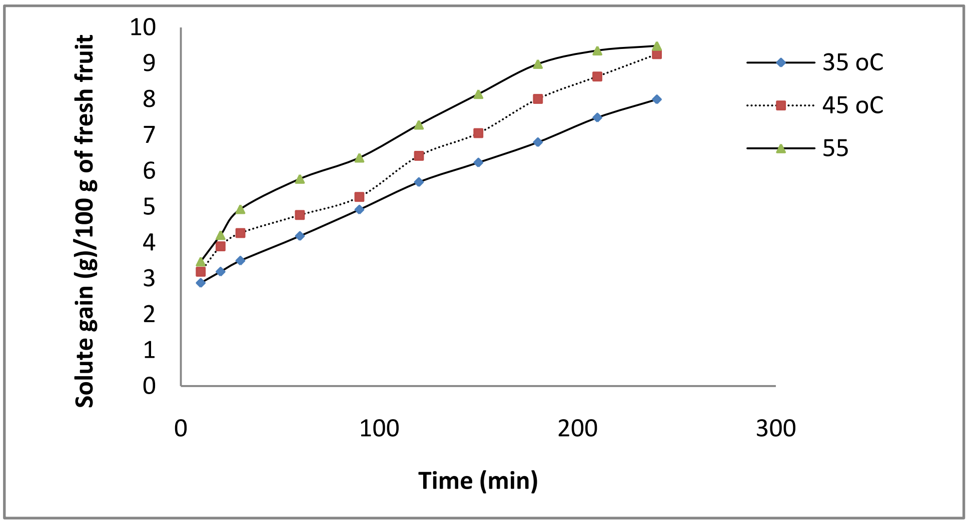

Fig 5: Effect of osmotic solution temperature and time on solute gain at 60 °Bx.

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