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Mass transfer kinetics and optimization during osmotic dehydration of beetroot (*Beta vulgaris L.*).

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Abstract - The present study was carried out to investigate the mass transfer kinetics and optimization during osmotic dehydration of beetroot. The samples were osmotically treated in different hypertonic sugar solution (55, 65 and 75 ^{0} Brix) with salt concentration of 5 % (w/v), at different solution temperature (30, 45 & 60 °C). Mass transfer kinetics was modeled according to Magee and Azuara model, and kinetic parameters were calculated. It was found that the magee's model was appropriate for predicting water loss (WL) and solute gain (SG), while Azuara's model fitted water loss as well as solute gain (SG) data represented more accurately the condition of the complete process close to equilibrium. Quadratic regression equations describing effects of process variables on water loss, solute gain and weight reduction were developed and optimization of osmotic dehydration was done using response surface methodology (RSM). The regression analysis revealed that linear terms of all process parameters have a significant effect on all the responses. The optimum conditions were found to be as sugar of 75 ^{0}Brix with 5% salt, solution temperature of 47.70 ^{0} C and immersion time of 120 min at constant osmotic solution to sample ratio of 4:1. At these optimum values, water loss, solute gain and weight reduction were observed as 28.78, 4.42 and 24.36 (g/100 g of initial mass) respectively.

Index Terms - Beetroot, osmotic dehydration, mass transfer kinetics, modeling, and optimization

I. INTRODUCTION

Osmotic dehydration (OD), initially proposed by Ponting (1973), has been studied in recent decades, especially as a pre-treatment for foods to be subjected to air drying, freezing, freeze-drying and other processes, in order to guarantee and improve the composition of food by partial water removal and impregnation without affecting its integrity.
The sensory qualities of the food products with solute depend on the expected water loss (WL) to solid gain (SG) ratio. The prediction and control of WL/SG ratio resulting from a solute or solute combination is a basic requirement for process design. Solutes sugars (especially for fruits) and salts (for vegetables, fish, meat and cheese) are mostly used for osmotic treatment. Mixtures of solutes have also been used for both plant and animal treatment to obtain higher WL/SG ratios and to reduce impregnation. Salt and sucrose concentrations show a synergetic effect on food osmotic treatments, which has led researches to investigate optimum process conditions (Qi et al., 1999; Sereno et al., 2001; Mayor et al., 2007).

In the present work, osmotic dehydration was applied to beetroot because they are commonly used products and easy to store and process. Further, it has been chosen because it is a good source of vitamin C, folate, soluble and insoluble dietary fiber and antioxidants that are necessary in human nutrition and it can also be used as alternative for treatment of fever and constipation, amongst other ailments. The beetroot (*Beta vulgaris L.*) is considered a good model for dehydration studies because of homogeneity and extensive shelf-life that this vegetable tissue has.

Considering the potential importance of OD process for industrial applications, simple predictive models which supply further information on the variables that control the dehydration process (Azuara et al., 1992) have been developed. According to this purpose, numerous empirical models have been presented which establish direct relations between process variables and water loss (WL), solute gain (SG), etc. Among these models are the ones that use direct correlation such as Azuara's model (Azuara et al., 1992) and Magee's model as suggested by Magee et al., (1983), or the ones that utilize polynomial fitting (Shi et al., 2008).

Response surface methodology (RSM) has the ability to find a unique equation that can predict the evolution of process variables in a specific range of work. This ability can be used combined with other techniques to find optimal operating conditions in the food industry. In response surface methodology (RSM), several factors are simultaneously varied. The multivariate approach reduces the number of experiments, improves statistical interpretation possibilities and evaluates the relative significance of several affecting factors even in the presence of complex interactions. There are several work has been carried out on mathematical modeling and optimization of vegetables. However, no information is available on the statistical modeling of beetroot drying by osmotic dehydration. Hence the objectives of this study were to evaluate the adequacy of different empirical models to predict the evolution of water loss (WL) and Solute gain (SG) during osmotic dehydration (OD) and obtain optimal processing conditions of beetroot during osmotic dehydration in combined aqueous solution of salt and sugar, maximizing water loss (WL) and weight reduction (WR) and minimizing solute gain (SG) through response surface methodology (RSM).

II. MATERIAL AND METHOD

Sample preparation

Beetroots were procured from local market in a period between December and January and then stored at 5 ^{0}C prior to experiments. Beetroots were thoroughly washed with water to remove dirt and dust. The beetroots were peeled manually and cut into 10x 10x 3 mm slices. The average moisture content of the beetroot was found to be 79.17 % wb. Considering the greater effectiveness of a mixture of solutes over a single solute, a binary solution of salt with 5 % and sugar of 55–75 °Brix (w/v) was prepared with the proper amount of pure water considering the experimental design of Box and Behnken (1960). The experiments were conducted at temperatures of osmotic solution varied in the range of 30–60 °C. No blanching was done prior to osmosis as it is detrimental to the osmotic dehydration process due to loss of semi-permeability of cell membranes (Ponting, 1973) and reduction of β-carotene (Negi and Roy, 2000).

Osmotic dehydration

For each experiment, 10 g of beetroots were put into glass beakers of 250ml containing calculated volumes of osmotic solutions for different concentrations and thereafter placed inside a temperature and agitation controlled incubator. To prevent evaporation from the osmotic solution, glass beakers were covered with a plastic wrap during the experiments. For each experiment, the ratio of osmotic solution to beetroot sample was kept as 4:1 in order not to dilute the osmotic solution by water removal during the runs, which can lead to local reduction of the osmotic driving force during the process. During experimentation, it was assumed that the amount of solid leaching out of carrots during osmosis was negligible (Biswal and Bozorgmehr, 1992; Lazarides et al., 1995). At specified duration, the beetroot slices were removed from the osmotic solutions and rinsed with water to remove surplus solution adhering to the surfaces. These osmotically dehydrated slices were then spread onto absorbent paper to remove free water present on the surface. Beetroot sample of 3-5 g was used for determination of dry matter using oven-drying. All the experiments were replicated twice and the average value was taken for further calculations.

Mass transfer parameters

Mass exchange between the osmotic solution and beetroot sample during osmotic dehydration were evaluated using the parameters such as water loss (WL), solute gain (SG) and weight reduction (WR). In order to account for initial weight differences between the samples, water loss (WL), solid gain (SG) and weight reduction (WR) were calculated using the given equations:

$$WL = \frac{(M_t - M_0)}{M_0} \quad (1)$$

$$SG = \frac{(m_t - m_0)}{M_0} \quad (2)$$

$$WR = WL - SG \quad (3)$$

where WL is water loss (g /100 g of initial mass), SG is solute gain (g /100 g of initial mass), WR is weight reduction (g /100 g of initial mass), M_o is initial water mass (g), M_t is the water mass at time t in the sample (g), m_o is initial total solids (g), m_t is total solids at time t in the sample (g), respectively.

Kinetic models for osmotic dehydration

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

Magee's model

This model establishes that WL and SG vary linearly with the square root of time during osmotic dehydration (Magee et al, 1983):

$$WL_\tau \ or\ SG_\tau = A + k\sqrt{t} \quad (4)$$

Where, WL_τ is the water loss at time t, SG_τ is the solids gain at time t, A and k are model fitting parameters. Coefficients k represents the rate of water removal or solids intake, because of the osmotic-diffusive mechanism; meanwhile, A represents the contribution of the hydrodynamic mechanism, because of the action of capillary pressures at very short times, for mass transfer of water or solids.

Azuara's model

Azuara et al. (1992) modeled the rate of water loss (WL) and solute gain (SG) as function of time using a mass balance on water movement inside the food, obtaining equations with two fitting parameters. In the model formulation, the following relation for WL is established:

$$WL_\tau = \frac{S_1\, t \times WL_\infty}{1 + S_1\, t} \quad (5)$$

Where $WL\infty$ is the corresponding value at infinite time (i.e., at equilibrium) and S_1 is the constant related to the outward water diffusion rate in the food. Equation 5 can be expressed in linear form as:

$$\frac{t}{WL_\tau} = \frac{t}{WL_\infty} + \frac{1}{S_1\, t} \quad (6)$$

The water loss at equilibrium (WL∞) and the constant S_1 were estimated from the slope and intercept of the plot (t/WL_T) vs. t using the eqn 6. Thus, the equations for SG can be written as:

$$SG_\tau = \frac{S_o\, t \times SG_\infty}{1 + S_o\, t} \qquad (7)$$

$$\frac{t}{SG_\tau} = \frac{t}{SG_\infty} + \frac{1}{S_o\, t} \qquad (8)$$

Where, SG∞ is the corresponding value at infinite time (i.e. at equilibrium) and S_0 is the constant related to the incoming solute diffusion rate in the food. Similarly to WL∞ and S_1, SG∞ and S_0 parameters are obtained from the straight line (t/SG_T) vs. t using equation 8.

The Magee's and Azuara's models adequacy for the best fitting of experimental data was evaluated by obtaining the coefficient of determination R^2 and least RMSEand percent mean relative deviation of modulus (P) using following equations:

$$RMSE = \sqrt{\left[\frac{\sum_{\iota=1}^{N}(Experimental\ value - Predicted\ value)^2}{N}\right]} \qquad (9)$$

$$P\ (\%) = \frac{100}{N}\sum_{\iota=1}^{N}\left|\frac{Experimental\ value - Predicted\ value}{Experimental\ value}\right| \qquad (10)$$

The nonlinear regression and statistical analysis was performed by using SPSS version 16.0 software.

Process optimization and statistical analysis

Polynomial regression

With the aim to predict the evolution of osmotic dehydration and investigate the effect of each process variable (immersion time, solution concentration, and solution temperature) at three levels each in the mass transfer kinetics, a second order polynomial model was developed for water loss (WL), solute gain (SG) and weight reduction(WR) using multiple linear regressions. The model proposed for each kinetic variable is described as follows:

$$y_k = \beta_0 + \sum_{i=1}^{n}\beta_\iota x_\iota \sum_{i=1}^{n}\beta_{ii}{x_i}^2 \sum_{i-1}^{n-1}\sum_{j=i+1}^{n}\beta_{ij}x_i x_j \qquad (11)$$

Where, y_k represents response variables (y_1 = water loss, y_2 = solute gain and y_3 = weight reduction) x_i represents the coded independent variables and β_{ko}, β_{ki}, β_{kii}, β_{kij} represent constant coefficients. Three dimensional surface plots were generated as a function of two factors while keeping other factor at optimum level with the same software.

Statistical analysis

The analysis of variance (ANOVA) of the polynomial models was carried out using Design Expert 8.0.7.1 software and the adequacy of the model was tested using Fischer test & P value, coefficient of correlation (R^2) and lack of fit test. The models were considered adequate when the calculated Prob> F was less than 0.05, R^2>0.90 and lack of fit test (L_oF) was insignificant.

III. RESULT AND DISCUSSION

The effect of all process variables including solution concentration (salt and sugar), solution temperature and immersion time on mass transfer kinetics namely water loss, solute gain and weight reduction was investigated and response surface plots were plotted as shown in Fig 1. The detailed description of effect of process variables on mass transfer kinetics and its modeling has been discussed as below:

Effect of Process variables on on mass transfer kinetics

Effect of immersion time

From Figure 1 and 2 representing effect of immersion time on water loss (WL), solute gain (SG) and weight reduction (WR), it was observed that all the mass transfer parameters increased rapidly with increase in immersion time in comparison to later stage of osmotic dehydration. This might be due to facts that with passage of immersion time the osmotic driving force for water diffusion from sample to solution and solute transfer from solution to sample decreased. Further in salt-sugar mixed osmotic solution, sugar molecules due to high molecular weight accumulated in thin sub surface layer resulting in extra barrier to mass transfer, whereas salt molecules due to smaller size easily diffused inside the cell membrane and generated concentration gradient as a driving force for mass transport during osmotic dehydration. Besides, salt concentration also inhibited the formation of compacted surface layer of sugar and allowed higher transfer rate of water as well as solute. Similar results have been reported by Sereno et al., (2001) and Jokic et al., (2007). Conway et al., (1983) has 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.

Effect of solution concentration (salt and sugar mixture)

The effect of solution concentration on mass transfer (water loss, solute gain and weight reduction) has been presented in Figure 1. The figures showed that increase in solution concentration resulted gradual increase in rate of both water loss and solute gain, consequently the weight reduction. This was expected due to accumulation of solute with higher molecular weight possing an additional resistance to diffusion of water and solute. However, presence of salt prevented the formation of crust barrier and led to higher rate of water removal and solute uptake, probably due to an increase in osmotic pressure gradient and consequent increase in porosity and shrinkage of tissues that allowed higher rate of water removal and weight reduction than solute uptake.

Effect of solution temperature

The temperature of osmotic solution also play great role in kinetics of mass transfer during osmotic dehydration. The effect of changing solution temperature on water loss, solute gain and weight reduction has been shown in Figure 2. It was observed that the all the response variables i.e water loss, solute gain and weight reduction increased with increase in solution temperature. This might be due to swelling and plasticizing of cell membrane that promote faster diffusion of water from sample to solution and in the same time higher temperature reduced the solution viscosity of the osmotic medium and resulted in better water transfer characteristics at the product surface. On the other hand, solute transfer within product was found to increase with increase in solution temperature but at slower rate in comparison to water loss. This might be probably due to high molecular weight of solute and concentration of osmotic medium. Although increase in solution temperature promotes higher water removal from sample, but temperature above 60 °C modify the tissue structure and results impregnation phenomenon. Further higher temperature also results enzymatic browning and flavor deterioration as reported by Lenart and Flink (1984). Therefore, best processing temperature should be decided on the basis of foodtissue structure.

Modeling of mass transfer kinetics

The kinetic models (Magee and Azuara) were used to fit mass transfer parameter data over processing time as function of different concentrations of hypertonic solution and temperatures. The values of model parameters, together with the determination coefficient, RMSE and percent mean relative deviation of modulus (P) are reported in Table 1. As there was not any fixed trend in the values of R^2, RMSE and P % values among different experiments, so average value of 9 experiments were determined to check the adequacy of fitted models.

The constant A representing the hydrodynamic mechanism for the action of capillary pressures at very short times for mass transfer of water showed a significant increase with increase in concentration as well as temperature of the osmotic solution, whereas for solute gain, A did not showed any clear trend with solution concentration as well as solution temperature. On the other hand, parameter k representing the rate of solute uptake, showed increasing trend with increase in solution concentration as well as temperature, if processed with high concentration (above 65 °Brix) at solution temperature over 45 °C. This investigation was in agreement with obtained result that solute uptake increased with increase in solution concentration and temperature. However, parameter k of Magee model for rate of water removal represented abrupt variation which was not in agreement with results obtained in present study that water loss increased with increase in the concentration and temperature of the osmotic solution. This implied that Magee model was not effective in describing the mass transfer characteristics (rate of water removal).On the other hand, the constant S_1 of Azuara model, which represents the water removal rate showed that rate of water diffusion increased with increase in concentration only if processed at higher temperature i.e over 45 °C. However, for solute uptake parameter S_0 decreased with increase in solution concentration as well increase temperature. Nevertheless, Azuara model was effective to identify the equilibrium conditions as much for water loss(WL) as for solute gain (SG) by obtaining the parameters $WL_\infty$and SG_∞ respectively, presenting equilibrium values for the obtained WL and SG in salt+sugar solutions (Table 1) for beetroot. The obtained results, and average major values of coefficient of determination (R^2) and the minor average values of RMSE and P (%)) showed that Magee model has a very good fit to short times of processing with higher concentration and temperature, where the rate of mass transfer maximized whereas, Azuara model, adequately followed the evolution of the complete dehydration process tending to equilibrium, which occured at long times (not experimentally verified during the studied period of dehydration).

Optimization

Although from modeling with empirical equations a suitable monitoring of the different stages in osmotic dehydration process, an evaluation of the effect of different factors and a visualizing of certain optimal zones could be performed, this approach is not enough for the accurate identification of the optimal operation conditions. Therefore experimental data was fitted second order response surface model and three equations satisfactorily describing the relationship between process variables and response variables were obtained by analyzing the experimental data using RSM as shown below:

$$\text{Water loss(WL)} = 29.11 + 1.28\,\beta_1 + 1.15\beta_2 + 2.71\beta_3 - 0.53\beta_{12} - 0.42\beta_{13} + 0.22\beta_{23} - 0.02{\beta_1}^2 - 0.81{\beta_2}^2 + 0.65{\beta_3}^2$$

$$\text{Solute gain(SG)} = 5.23 + 0.23\beta_1 + 0.10\beta_2 + 1.06\beta_3 - 0.03\beta_{12} + 0.01\beta_{13} + 0.03\beta_{23} - 0.09{\beta_1}^2 + 0.07{\beta_2}^2 - 0.08{\beta_3}^2$$

$$\text{Weight Reduction(WR)} = 23.88 + 1.05\beta_1 + 1.05\beta_2 + 1.65\beta_3 - 0.50\beta_{12} - 0.43\beta_{13} + 0.19\beta_{23} - 0.11{\beta_1}^2 - 0.88{\beta_2}^2 + 0.73{\beta_3}^2$$

Where, 1, 2, and 3 represented coded values of the test variables solution concentration, solution temperature and immersion time respectively.

The results of multiple linear regression equation conducted for the second order response surface model were obtained and presented in Table 2. The significance of each coefficient was determined through the fischer F test and P values (Table 2). The larger the magnitude of the F value and the smaller the P value, the more significant is the corresponding coefficient (Morgan,1991). However, values of "Prob> F" less than 0.05 indicate model terms are significant. In present study, it was observed that linear effect of all variables namely solution concentration, solution temperature and immersion time had significant effect on water loss, solute gain and weight reduction as the P values were less than 5 %. However, among quadratic effects of process variables, immersion time had more effect on water loss and weight reduction and solution concentration had more effect on solute gain as F values were higher compared to other factors. The goodness of fit of model was verified by determination of regression coefficient (R^2> 0.9). The coefficient of $R^2$was calculated to be 0.9403, 0.9736 and 0.8805 for water loss, solute gain and weight reduction respectively. Other authors obtained coefficients of regression of different products subjected to osmotic dehydration, e.g. green peppers (Ozdemir et al., 2008), carrots cubes (Singh et al., 2010) and cantaloupe (Corzo and Gomez, 2004) using the same predictive polynomial equation (eqn 11). In agreement with obtained results, positive and negative values in the linear, interaction and quadratic terms depending upon the best fitting of the experimental data were evaluated and presented in Table 2. It was observed that β_1, β_2,β_3, β_{23} and ${\beta_3}^2$ have positive effect on water loss and weight reduction, whereas β_{12}, β_{23}, ${\beta_1}^2$ and ${\beta_2}^2$ had negative influence on both water loss and weight reduction. On the other hand, for solute uptake all the terms had positive effect except for β_{12} and ${\beta_3}^2$.

Graphical multi-response optimization technique was adopted to determine the workable optimum conditions for the osmotic dehydration of beetroot. The contour plots (not shown) for all responses were superimposed and regions that best satisfy all the constraints were selected as optimum conditions. These constraints resulted in 'feasible zone' of the optimum conditions. The optimum range of process parameters for osmosed beetroot was: 55-65 ^{0}B of sugar concentration with constant salt concentration of 5%, 30-60^{0}C of solution temperature and 120-240 minutes of immersion time in order to optimize the process parameters for osmotic dehydration of beetroot by numerical optimization; which finds a point that maximizes the desirability function. The optimum operating conditions for solution concentration, solution temperature and immersion time was 75^{0}Brix with 5 % salt, 47.70^{0}C and 120 minutes. Corresponding to these values of process variables, the value of water loss was 28.78, solute gain 4.42 and weight reduction 24.36 g/100 g of initial mass. The overall desirability was 0.645.

Table I: Model's parameters and goodness of fit for mass transfer during osmotic dehydration of beetroot

WATER LOSS											
MODELS		**MAGEE**					**AZUARA**				
Temperature (°C)	**conc.**	**A**	**k**	**R^2**	**RMSE**	**P %**	**S_1**	**WL∞**	**R^2**	**RMSE**	**P %**
30	55	-1.678	0.49	0.995	0.095	0.39	0.064	27.193	0.997	0.133	3.84
	65	-1.692	0.512	0.996	0.332	1.27	0.042	32.555	0.993	0.182	5.65
	75	-1.413	0.508	0.993	0.386	1.33	0.042	33.133	0.993	0.187	5.58
45	55	-1.66	0.495	0.996	0.769	2.68	0.030	34.396	0.981	0.289	8.43
	65	-0.746	0.446	0.962	0.817	2.92	0.035	34.794	0.985	0.256	8.21
	75	-0.582	0.454	0.968	0.312	1.05	0.041	35.393	0.993	0.172	5.74
60	55	-1.583	0.498	0.995	0.403	1.04	0.035	34.372	0.989	0.221	6.07
	65	-0.695	0.449	0.97	0.739	2.55	0.036	34.730	0.987	0.235	7.71
	75	-0.542	0.454	0.972	0.401	1.32	0.043	35.120	0.995	0.147	5.22
Average				0.983	0.473	1.617			0.990	0.202	6.272
SOLUTE GAIN											
Temperature (°C)	**conc.**	**A**	**k**	**R^2**	**RMSE**	**P %**	**S_O**	**SG∞**	**R^2**	**RMSE**	**P %**
30	55	0.563	17.209	0.997	0.111	2.69	17.317	0.002	0.907	1.317	3.34
	65	0.878	16.480	0.987	0.104	2.52	17.172	0.002	0.916	1.258	3.52
	75	0.884	16.930	0.983	0.141	3.62	13.799	0.004	0.976	0.818	2.71
45	55	1.071	14.004	0.956	0.108	2.69	17.088	0.002	0.896	1.427	3.85
	65	0.964	16.481	0.940	0.295	9.00	10.433	0.006	0.822	3.183	12.21
	75	0.968	17.649	0.991	0.276	7.68	10.346	0.007	0.867	2.698	11.41
60	55	1.044	15.186	0.987	0.115	2.73	15.194	0.003	0.970	0.829	2.48
	65	0.969	16.730	0.951	0.267	7.94	10.346	0.006	0.857	2.821	11.17
	75	0.962	18.045	0.985	0.259	7.09	10.262	0.007	0.886	2.501	10.88
Average				0.975	0.186	5.107			0.900	1.872	6.841

Table 2: Second order polynomial models for response variables during osmotic dehydration of beetroot

Source		WL			SG			WR		
	df	coefficients	F value	p-value	coefficients	F value	p-value	coefficients	F value	p-value
β_0	9	29.11*	12.26	0.0016	5.23*	28.71	0.0001	23.88*	5.73	0.0157
β_1	1	1.28*	16.29	0.0050	0.23*	11.69	0.0111	1.05*	9.74	0.0168
β_2	1	1.15*	13.10	0.0085	0.10	2.25	0.1775	1.05*	9.72	0.0169
β_3	1	2.71*	73.03	< 0.0001	1.06*	242.12	< 0.0001	1.65*	24.13	0.0017
β_{12}	1	-0.53	1.38	0.2784	-0.03	0.08	0.7843	-0.50	1.11	0.3271
β_{13}	1	-0.42	0.88	0.3806	0.01	0.01	0.9205	-0.43	0.82	0.3951
β_{23}	1	0.22	0.24	0.6390	0.03	0.08	0.7843	0.19	0.16	0.6972
β_1^2	1	-0.02	0.00	0.9670	0.09	0.96	0.3590	-0.11	0.06	0.8168
β_2^2	1	-0.81	3.42	0.1070	0.07	0.55	0.4818	-0.88	3.61	0.0993
β_3^2	1	0.65	2.23	0.1788	-0.08	0.68	0.4379	0.73	2.50	0.1580
Lack of fit	3		0.79	0.5608		0.10	0.9570		0.54	0.6818
R^2			0.901			0.9736			0.8805	

Note: * Significant at 5 % level, 1= solution concentration, 2= solution temperature and 3= immersion time

IV. CONCLUSION

The concentration and temperature of the osmotic solution increased the transfer rate in all studied experiments, while the immersion time had just a more significant effect on mass transfer parameters. Magee model proved to be adequate for the prediction of mass transfer kinetics. The prediction of the evolution of the complete process to equilibrium, of the osmotic dehydration of beetroot, was adequately achieved through Azuara model. Response surface methodology was effective to determine the optimal processing conditions to maximize the water loss and weight reduction, and minimize the solute gain during the osmotic dehydration of beetroot. The analysis of variance showed significance from all second-order polynomial models developed for the three responses. The optimum operating conditions for solution concentration (sugar and salt), solution temperature and immersion time was 75^0Brix, 47.7^0C and 120 minutes with constant salt concentration of 5% and solution to sample ratio of 4:1 for beetroot of 3mm thickness. Corresponding to these values of process variables, the value of water loss was 28.78, solute gain 4.42 and weight reduction 24.36 g/100g of initial mass.

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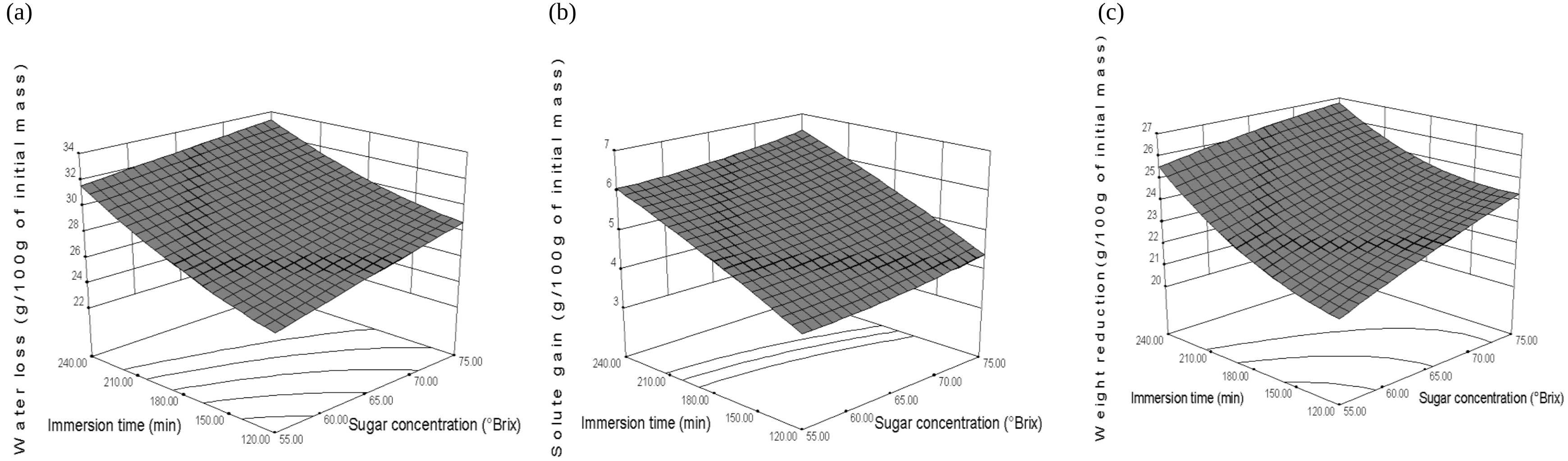

Figure 1: Combine effect of immersion time and sugar concentration with salt of 5% on (a) water loss, (b) solute gain and (c) weight reduction during osmotic dehydration

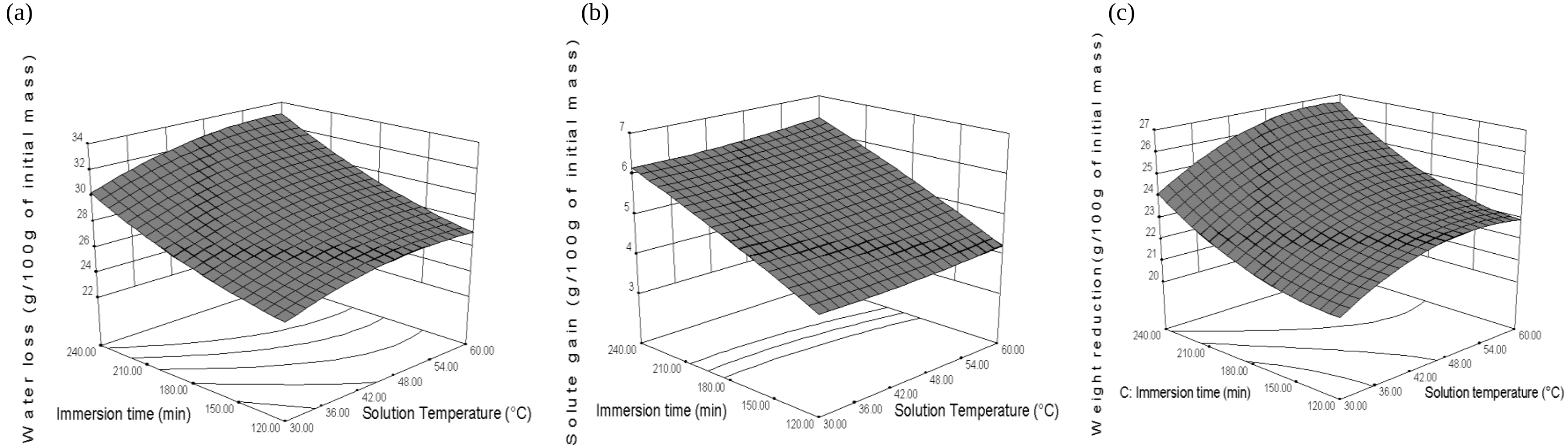

Figure 2: Combine effect of immersion and solution temperature on (a) water loss, (b) solute gain and (c) weight reduction during osmotic dehydration.