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# Optimisation of pumpkin mass transfer kinetic during osmotic dehydration using artificial neural network and response surface methodology modelling

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**RESEARCH ARTICLE**

## Abstract

In this study, the response surface methodology (RSM) was used to optimise osmo-dehydration of pumpkin cubes. Effect of different parameters including osmotic solution temperature in the range of 5 to 50 °C, the immersion time from 0 to 180 min and the concentration of osmotic solution (from 5% salt + 50% sucrose w/v to 15% salt + 50% sucrose w/v) on water loss (WL), solid gain (SG), weight reduction and final moisture content were investigated by central composite design. The optimum condition for osmotic dehydration was found to be at a temperature of 5 °C, an immersion time of 180 min and an osmotic solution concentration of 15% salt + 50% sucrose w/v. At this optimum condition WL, SG, weight reduction and moisture content were found to be 70.7 g/100 g initial sample, 10.2 g/100 g initial sample, 59.06 g/100 g initial sample and 0.64 g water/g dry matter, respectively. The comparison of the obtained results by artificial neural network and RSM modelling showed that the artificial neural approach has a higher ability in comparison with RSM modelling in predicting final moisture content ($R^2$=0.998 and 0.992, respectively).

**Keywords:** artificial neural network, osmotic dehydration, pumpkin, RSM

## 1. Introduction

Osmotic dehydration is the process during which partial removal of water from the cellular materials takes place by placing material in a hypertonic concentrated solution of soluble solute. Osmotic dehydration of pumpkin can be a useful technique to preserve and obtain new processed products of interest to consumer. Up to date few works can be found in the literature dealing with mass transfer during soaking processes of pumpkins. For instance, De Souza Silva *et al.* (2011) investigated the effect of osmotic dehydration process for low temperature blanched pumpkin. The kinetic modelling of osmotic dehydration was performed using 50% and 65% sucrose solutions on blanched samples. The diffusivity values for the water and sucrose were similar, showing greater gains of solute than loss of water in many samples. Also, blanching affected the colour of the pumpkin, whereas osmotic dehydration did not change it significantly. However, the impregnation process maintained or even increased the tissue firmness compared to the blanching method. As well, Kowalska *et al.* (2008) studied the effect of blanching and freezing on osmotic dehydration of pumpkin. Lenart *et al.* (1993) used several sugars during osmotic dehydration of pumpkin. They showed that water loss (WL) was higher than solids gain. They also found that solid gain (SG) increased when the molecular weight of the sugar decreased. Kowalska and Lenart (2001) used sucrose solutions in the osmotic dehydration of apple, carrot and pumpkin. Among these fruits, pumpkin showed the highest values of WL and the lowest amount of solids gain. Chang *et al.* (2003) used mixed sugar and salt solutions in the dehydration of green pumpkins. They showed that the rate of dehydration increased by increase of process temperature and osmotic solution concentration. Singh *et al.* (2010) elaborated osmotic dehydration process of carrot cubes in mixtures of sucrose and sodium chloride solutions by response surface methodology (RSM). Statistical analysis of results revealed that the linear terms of all the process variables have a significant effect on all the responses. Besides, the optimum osmotic dehydration process conditions for maximum WL, minimum solute gain, maximum retention of colour and sensory score were: 50°Brix + 15% w/v sodium chloride solution, solution temperature of 54.8 °C and 2 h dehydration time.

Artificial neural network (ANN) tool has been enforced as influential tool to predict the food properties changes for the period of dehydration. Several researches have been done in field of food modelling via ANN. For example, Shafafi Zenoozian and Devahastin (2009) illustrated the dehydration behaviour of pumpkin during drying through wavelet transform coupled with ANN to predict the food properties. Lertworasirikul and Saetan (2010) studied the application of ANN modelling for mass transfer during osmotic dehydration of kaffir lime peel. The results declared that increasing solute concentration and process temperature resulted in a higher reduction in moisture contents of kaffir lime peel and increase in WL and SG rates. Multilayer feed forward neural network was proposed to predict percentages of WL and SG of kaffir lime peel during osmotic dehydration based on three processing factors as inputs. The best network with the lowest average mean squared error of 0.0066 and the highest average correlation coefficient ($R^2$) of 0.9725 from normalised training and validating data sets was composed of one hidden layer with five hidden neurons and used Levenberg-Marquardt algorithm as a training algorithm.

The objective of this research was determining the optimum processing conditions during osmotic dehydration of pumpkin by using RSM. As well, in this paper final moisture content of pumpkin was predicted by different activation function of ANN.

## 2. Materials and methods

### Raw material preparation

Fresh pumpkins (*Cucurbita* spp.) used in this experiment were purchased from the local market. The fruits of fresh pumpkin were harvested on month January in 2011. Fruits were stored at 5 ± 0.5 °C and 80-90% relative humidity in a refrigerator until use (1-2 months). First, the pumpkins were washed with water and then the peeling was accomplished manually by stainless steel hand-peelers. Pumpkin samples were cut and sliced to obtain cubes with approximately $10 \times 10 \times 5$ mm$^3$ (length, width and height, respectively). The initial moisture content was determined by direct heating in a laboratory oven (model UNE 400 PA; Memmert, Scheabach, Germany) at 105 °C for 48 h according to AOAC method 931.04 (AOAC, 1990). The average initial moisture content was found to be 92.11±1 (% wet basis; w.b.).

### Osmotic dehydration process and assessment of the final equilibrium water loss and solid gain

The osmotic process was carried out at different osmotic solution concentrations (5% salt + 50% sucrose w/v, 10% salt + 50% sucrose w/v and 15% salt + 50% sucrose w/v). Pumpkin samples were weighted and placed in a 100 ml beaker at three different temperatures (5, 25 and 50 °C). In order to prevent dilution of osmotic solution by water removal from the sample during the experiment, the ratio of product to solution was kept at 1:20 (w/w) (Kaymak-Ertekin and Sultanoglu, 2000). Samples were withdrawn from the solution at time interval of 60, 120 and 180 min after immersion, drained with deionised water and they were smoothly blotted with tissue paper to remove osmotic solutions stuck to the samples and finally, were weighted. Three pieces of the samples (6-12 g) were used to determine the average moisture content (% w.b.) by using a hot oven (105 °C) until constant weight reached(AOAC, 1990). The following osmotic criteria's have been determined for all samples (Chenlo *et al.*, 2006):

$$WL = \frac{(1-S_0)\cdot m_0 - (1-S_t)\cdot m_t}{S_0\cdot m_0} \tag{1}$$

$$SG = \frac{S_t\cdot m_t - S_0\cdot m_0}{S_0\cdot m_0} \tag{2}$$

$$WR = WL - SG \tag{3}$$

Where $m_0$ is the initial mass of the sample, $m_t$ is the sample mass at time $t_0$, $S_0$ and $S_t$ are the solids content in osmotic solution prior to osmotic dehydration and the solids content in osmotic solution during osmotic dehydration, respectively, and WR is the weight reduction.

As well, in this research, the two parameter models, developed by Azuara *et al.* (1992), are used to predict WL and SG at equilibrium conditions. This model is able to predict the kinetics of the osmotic process and the equilibrium point, using data obtained during a relatively short period of time i.e. from the initial portion of the dehydration curve. The linear form of these equations are as following:

$$\frac{t}{WL_j} = \frac{1}{S_1 WL_\infty} + \frac{t}{WL_\infty} \tag{4}$$

$$\frac{t}{SG_j} = \frac{1}{S_2 SG_\infty} + \frac{t}{SG_\infty} \tag{5}$$

Where $WL_j$ and $SG_j$ are the water loss (g/100 g fresh sample) and solid gain (g/100 g fresh sample) at time t (min), respectively, $WL_\infty$ and $SG_\infty$ are the corresponding quantities at equilibrium, $S_1$ and $S_2$ (1/min) are the model constants (rate constants) related to the rate of water diffusion out of food and solute diffusion into the food, respectively. The equilibrium water loss ($WL_\infty$) and solid gain ($SG_\infty$) are obtained from plots of $t/WL_j$ and $t/SG_j$ versus t, using $WL_j$ and $SG_j$ values, evaluated from the experimental data at different times.

### Experimental design

The experimental design adopted in this study was a face-centred central composite design (CCD). The three independent variables such as osmotic solution concentration ($X_1$; % w/v), immersion time ($X_2$; min), and osmotic temperature ($X_3$; °C) and the four dependent variables including water loss ($Y_1$; g/100 g fresh sample), solid gain ($Y_2$; g/100 g fresh sample), weight reduction ($Y_3$; g/100 g fresh sample) and moisture content ($Y_4$; g water/g dry matter) were investigated.

CCD is the most popular design in many classes of RSM designs (Khuri and Cornell, 1987). For each experiment, three different levels in coded form, are -1, 0, +1. These levels were computed based on the following equation:

$$\text{Coded amount} = \frac{R - [(X_j + X_i)/2]}{(X_j - Xi/2)} \tag{6}$$

In this equation, R is the actual value in the uncoded (original) units of the $i^{th}$ factor, $X_i$ is the low level of the $i^{th}$ factor, and $X_j$ is the high level of the $i^{th}$ factor. The levels of the independent variables in coded and actual form are given in Table 1.

The experimental design along with values of various responses, are given in Table 2. Design-Expert statistic software (version 6.01, Advanced Graphics Software;

**Table 1. The levels of different osmotic variables in coded and uncoded forms for the dehydration process**

| Coded levels | Uncoded (actual) amount of process variables | | |
|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ |
| -1 | 50% sucrose + 5% NaCl salt | 60 | 5 |
| 0 | 50% sucrose + 10% NaCl salt | 120 | 27.5 |
| +1 | 50% sucrose + 15% NaCl salt | 180 | 50 |

$X_1$ = osmotic solution concentration (% w/v); $X_2$ = immersion time (min); $X_3$ = osmotic temperature (°C).

**Table 2. Experimental conditions and observed response values of central composite design**

| Run | Osmotic process variables | | | Responses | | | |
|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | $Y_1$ | $Y_2$ | $Y_3$ | $Y_4$ |
| 1 | -1 | -1 | -1 | 50.01 | 6.308 | 43.70 | 1.66 |
| 2 | 0 | 0 | 0 | 61.54 | 14.11 | 47.42 | 1.42 |
| 3 | 0 | 0 | 0 | 60.34 | 13.1 | 46.4 | 1.50 |
| 4 | 0 | -1 | 0 | 53.03 | 11.60 | 41.42 | 2.12 |
| 5 | -1 | 0 | 0 | 57.16 | 11.96 | 45.2 | 1.35 |
| 6 | 0 | 0 | 0 | 62.54 | 13.5 | 46.42 | 1.37 |
| 7 | +1 | -1 | +1 | 63.76 | 19.41 | 44.35 | 1.15 |
| 8 | -1 | -1 | +1 | 54.14 | 12.70 | 41.43 | 1.66 |
| 9 | +1 | +1 | +1 | 76.68 | 25.99 | 50.69 | 0.63 |
| 10 | 0 | 0 | 0 | 60.90 | 15.11 | 45.9 | 1.39 |
| 11 | 0 | +1 | 0 | 67.24 | 15.95 | 51.29 | 1.06 |
| 12 | 0 | 0 | +1 | 65.99 | 18.99 | 47.00 | 1.23 |
| 13 | +1 | 0 | 0 | 68.46 | 16.43 | 52.03 | 1.29 |
| 14 | +1 | +1 | -1 | 69.16 | 10.15 | 59.00 | 0.63 |
| 15 | -1 | +1 | -1 | 59.63 | 7.496 | 52.14 | 1.35 |
| 16 | 0 | 0 | 0 | 63.53 | 12.52 | 49.42 | 1.43 |
| 17 | 0 | 0 | -1 | 60.99 | 8.101 | 52.88 | 1.23 |
| 18 | 0 | 0 | 0 | 62.82 | 13.11 | 48.62 | 1.38 |
| 19 | -1 | +1 | +1 | 63.77 | 16.96 | 46.80 | 1.35 |
| 20 | +1 | -1 | -1 | 59.99 | 8.763 | 51.22 | 1.15 |

$X_1$ = osmotic solution concentration (% w/v); $X_2$ = immersion time (min); $X_3$ = osmotic temperature (°C); $Y_1$ = water loss (g/100 g fresh sample); $Y_2$ = solid gain (g/100 g fresh sample); $Y_3$ = weight reduction (g/100 g fresh sample); $Y_4$ = moisture content (g water/g dry matter).

Minneapolis, MN, USA) was used to fit response surfaces and optimise dehydration process. Experimental data were fitted to a second order polynomial model and regression coefficients obtained. The generalised second order polynomial model used in response surface analysis was as follows:

$$Y_k = \beta_{k0} + \sum_{i=1}^{3}\beta_{ki}X_i + \sum_{i=1}^{3}\beta_{kii}X_i^2 + \sum_{i=1}^{2}\sum_{j=i+1}^{3}\beta_{kij}X_iX_j + \varepsilon_k \tag{7}$$

In this model, $\beta_{kn}$ are constant regression coefficients and $X_i$ are the factors.

### Artificial neural network

The ANN process was used according to Aghajani *et al.* (2012). In short, a multilayer perception (MLP) network is one of the most popular and successful neural network architectures, suited to a wide range of engineering application involved drying (Aghajani *et al.*, 2012; Kashiri *et al.*, 2012; Mousavi and Javan, 2009):

$$y_j = \sum_{i=1}^{n} f(w_{ij}x_i) + b_j \tag{8}$$

Where $y_j$ is the net input of each neuron in hidden and output layers, $x_i$ is input, n is number of inputs to the neuron, $w_{ij}$ is the weight of the connection between neuron i and neuron j and $b_j$ is the bias associated with $j^{th}$ neuron (Mohebbi *et al.*, 2010). A schematic structure of a perceptron neural network is shown in Figure 1. In this network, the input layer consists of 3 neurons (osmotic solution concentration ($x_1$),temperature ($x_2$) and processing time ($x_3$)) and the output layer contains one neuron (final moisture content ($y$)).

The back propagation algorithm was used for training of ANN model (Singh and Pandey, 2011). In order to optimise the ANN, different factors must be evaluated. In the current study, 1-2 hidden layers with 2-20 neurons per hidden layer, the learning rate of 0.4, the momentum coefficient of 0.9 and the activation functions of sigmoid logarithms and hyperbolic tangent in each hidden and output layer were used in order to find the best topology.

For ANN modelling, the data was randomly divided into three groups: 60% was used for training, 20% for validation and 20% for testing the network. Data modelling was accomplished in SPSS (version 19, Armonk, NY, USA). For determination of the best network arrangement, two criteria were used: the determination coefficient ($R^2$) and the mean relative error (MRE), which were calculated as follows:

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}(MR_{ANN,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(\overline{MR}_{ANN,i} - MR_{ANN,i})^2}\right] \tag{9}$$

$$MRE = \left(\frac{1}{N}\sum_{i=1}^{N}\frac{|(MR_{ANN,i} - MR_{exp,i})|}{MR_{exp,i}}\right) \times 100 \tag{10}$$

Where $MC_{ANN}$ is the predicted ANN output parameter, $MC_{exp}$ is the experimental data and N is the number of observations.

## 3. Results and discussion

### Effect of variables on water loss

Statistical analysis results of the osmotic dehydration process are shown in Table 3. The *P*-values indicate that all linear terms of process variables have significant effects on WL during osmotic dehydration (*P*<0.01). Generally, the effects of osmotic solution concentration on WL was somewhat greater than other factors (F=151.63). The results show that WL increased with increase of osmotic solution concentration and immersion time. The effect of changing

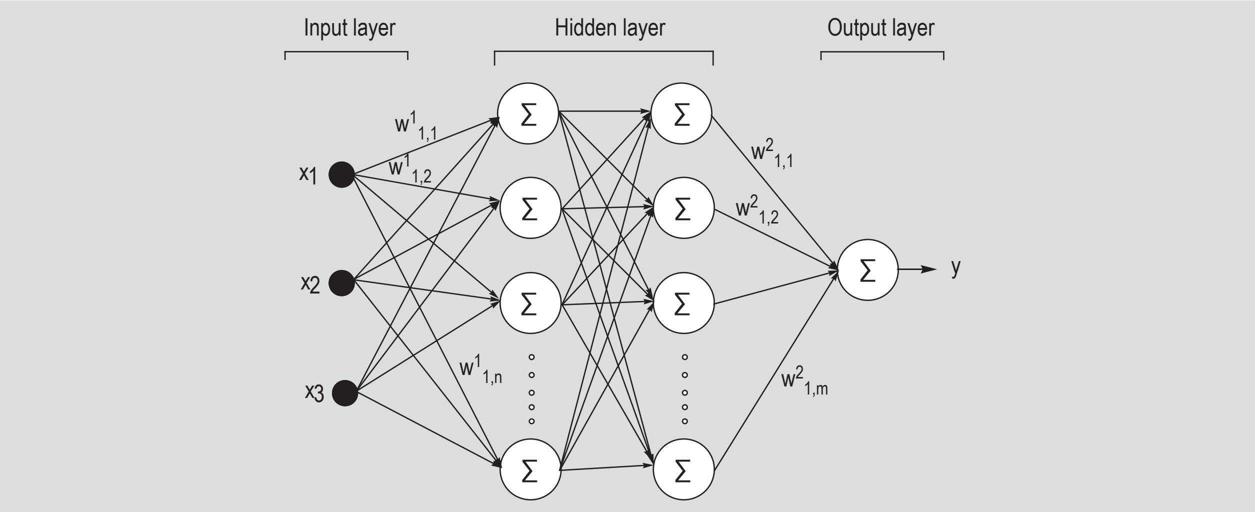

**Figure 1. Schematic structure of a perceptron neural network.**

**Table 3. Regression summary and ANOVA table for water loss in coded values of process variables.**

| Source | Regression coefficient ($\beta_n$) | Sum of squares | DF | Mean square | F value | Prob > F |
|---|---|---|---|---|---|---|
| Model | - | 661.26 | 6 | 110.21 | 58.76 | <0.0001 |
| Intercept | +52.47 | - | - | - | - | - |
| $X_1$ | -2.4854 | 284.37 | 1 | 284.37 | 151.63 | <0.0001 |
| $X_2$ | -0.022 | 101.02 | 1 | 101.02 | 53.86 | <0.0001 |
| $X_3$ | +0.109 | 60.42 | 1 | 60.42 | 32.22 | <0.0001 |
| $X_1^2$ | +0.170 | 0.75 | 1 | 0.75 | 0.4 | 0.5392 |
| $X_1X_2$ | +0.027 | 1 | 1 | 1 | 0.53 | 0.4777 |
| $X_1^2X_2$ | -1.29E-03 | 6.01 | 1 | 6.01 | 3.21 | 0.0967 |
| Residual | - | 24.38 | 13 | 1.88 | - | - |
| Lack of fit | - | 16.92 | 8 | 2.11 | 1.42 | 0.3646 |
| Pure error | - | 7.46 | 5 | 1.49 | - | - |
| Corrected total | - | 685.64 | 19 | - | - | - |
| R² | 0.9644 | - | - | - | - | - |
| Coefficient of variation | 2.21 | - | - | - | - | - |
| Standard deviation | 1.37 | - | - | - | - | - |

$X_1$ = osmotic solution concentration (% w/v); $X_2$ = immersion time (min); $X_3$ = osmotic temperature (°C); DF = degrees of freedom.

osmotic time and osmotic solution concentration on WL is given in Figure 2. Additionally, the interaction term $X_1X_2$ has a significant effect on WL. The quadratic term $X_1^2$ has a positive effect, whereas $X_2^2$ and $X_3^2$ have a negative effect on WL during osmotic dehydration. Similar results were reported by Garcia-Noguera *et al.* (2010) regarding the use of ultrasound treatment in osmotic dehydration of strawberry in sucrose osmotic solution. An increase in osmotic solution concentration causes water activity to reduce and increasing the necessary derived force for water removal from the sample, which led to an increase in WL of the sample (Eren and Kaymak-Ertekin, 2007). On the other hand, along with an increase in osmotic solution concentration, osmotic pressure difference was maintained in the longer time and resulted in a better mass transfer and WL increase (Togrul and Ispir, 2007).

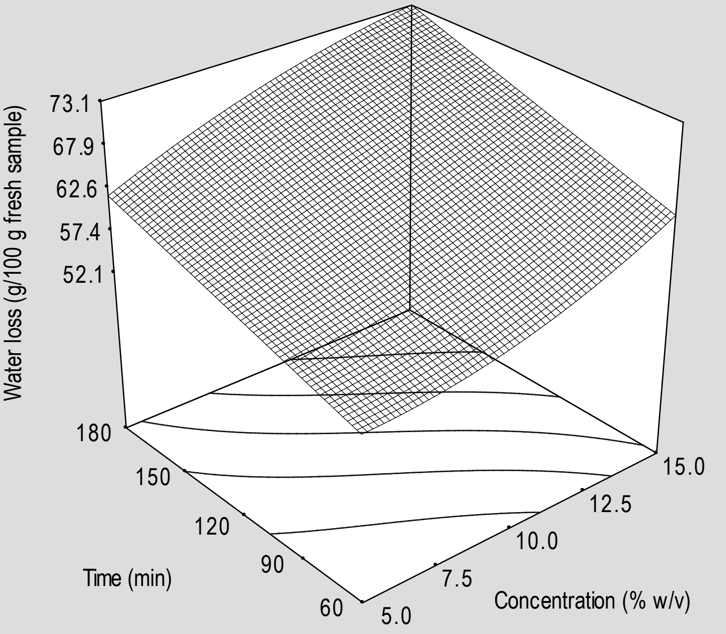

**Figure 2. Effect of osmotic solution concentration and immersion time on water loss during osmotic dehydration.**

### Effect of variables on solid gain

Table 4 indicates that linear terms of all the process variables have significant effects on SG during osmotic dehydration ($P<0.01$). The effect of osmotic temperature on SG was greater than other factors (F=557.51). On the other hand, the *P*-values indicate that all quadratic terms of process variables have non-significant effects on SG ($P<0.01$). Additionally, the interaction terms $X_1X_3$ and $X_2X_3$ have a positive effect (F=27.65 and 16.74, respectively), whereas the interaction $X_1X_2$ has a non-significant effect on SG.

As can be seen in Figure 3, SG increased with increase in process temperature and osmotic solution concentration. Similar observation has been reported by Singh *et al.* (2010). These results were presumably due to changes in physical properties of the samples and viscosity of the osmotic solution. Higher temperatures cause the increase in membrane permeability, which promotes swelling and plasticisation of the cell membranes. Furthermore, increasing temperatures causes a reduction in solution viscosity, reducing external resistance to mass transfer and making water and solute transport easier. These results

**Table 4. Regression summary and ANOVA table for solid gain in coded values of process variables.**

| Source | Regression coefficient ($\beta_n$) | Sum of squares | DF | Mean square | F value | Prob > F |
|---|---|---|---|---|---|---|
| Model | - | 401.75 | 5 | 80.35 | 157.99 | <0.0001 |
| Intercept | +4.25 | - | - | - | - | - |
| $X_1$ | +0.18 | 64.06 | 1 | 64.06 | 125.95 | <0.0001 |
| $X_2$ | +8.6E-03 | 31.58 | 1 | 31.58 | 62.09 | <0.0001 |
| $X_3$ | +0.027 | 283.53 | 1 | 283.53 | 557.51 | <0.0001 |
| $X_1X_3$ | +0.011 | 14.06 | 1 | 14.06 | 27.65 | 0.0001 |
| $X_2X_3$ | +7.64E-04 | 8.52 | 1 | 8.52 | 16.74 | 0.0011 |
| Residual | - | 7.12 | 14 | 0.51 | - | - |
| Lack of fit | - | 2.91 | 9 | 0.32 | 0.38 | 0.8994 |
| Pure error | - | 4.21 | 5 | 0.84 | - | - |
| Corrected Total | - | 408.87 | 19 | - | - | - |
| R² | 0.9826 | - | - | - | - | - |
| Coefficient of variation | 5.24 | - | - | - | - | - |
| Standard deviation | 0.71 | - | - | - | - | - |

$X_1$ = osmotic solution concentration (% w/v); $X_2$ = immersion time (min); $X_3$ = osmotic temperature (°C); DF = degrees of freedom.

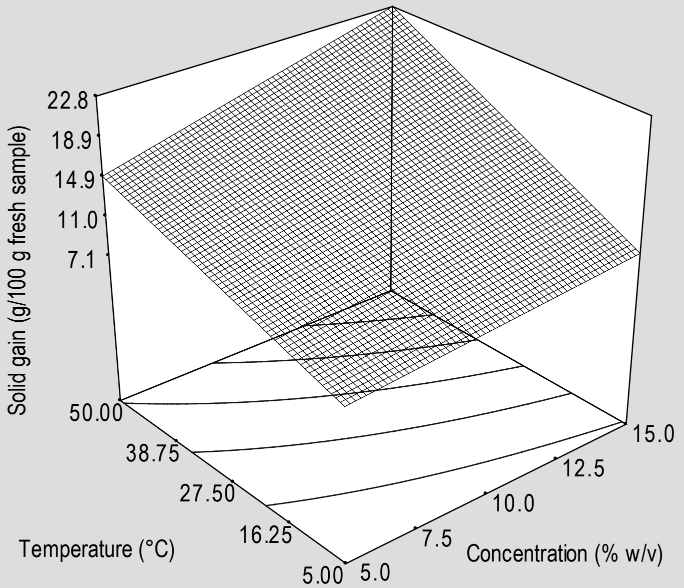

**Figure 3. The effect of osmotic solution concentration and temperature on solid gain during osmotic dehydration.**

were in agreement with other studies including Agarry *et al.* (2008), Hawkes and Flink (1978), Ispir and Togrul (2009), Lenart and Flink (1984). Also, an increase in osmotic solution concentration led to increased osmotic pressure, which can result in increased SG (Fernandes *et al.*, 2008).

### Effect of variables on weight reduction

As can be seen from Table 5, all linear terms of process variables have a significant effect on weight reduction during osmotic dehydration of pumpkin cubes ($P<0.01$). On the other hand, the effect of process time on weight reduction was somewhat higher than that of the other factors. Also, the quadratic terms $X_2{}^2$ and $X_3{}^2$ have a significant effect (F=3.63 and 11.28, respectively), whereas the quadratics term of $X_1{}^2$ has a negative effect on weight reduction. These results revealed that increase of osmotic solution concentration led to an increase in weight reduction. The effect of osmotic solution concentration and temperature on weight reduction is given in Figure 4.

**Table 5. Regression summary and ANOVA table for weight reduction in coded values of process variables.**

| Source | Regression coefficient ($\beta_n$) | Sum of squares | DF | Mean square | F value | Prob > F |
|---|---|---|---|---|---|---|
| Model | - | 327.48 | 6 | 54.58 | 36.74 | <0.0001 |
| Intercept | +33.92 | - | - | - | - | - |
| $X_1$ | +0.79 | 78.49 | 1 | 78.49 | 52.84 | <0.0001 |
| $X_2$ | +0.149 | 142.82 | 1 | 142.82 | 96.14 | <0.0001 |
| $X_3$ | -0.29165 | 82.18 | 1 | 82.18 | 55.32 | <0.0001 |
| $X_2{}^2$ | -3.6E-04 | 5.39 | 1 | 5.39 | 3.63 | 0.0791 |
| $X_3{}^2$ | +4.5E-03 | 16.75 | 1 | 16.75 | 11.28 | 0.0051 |
| $X_1X_3$ | -8.4E-03 | 7.2 | 1 | 7.2 | 4.85 | 0.0463 |
| Residual | - | 19.31 | 13 | 1.49 | - | - |
| Lack of fit | - | 9.5 | 8 | 1.19 | 0.61 | 0.7489 |
| Pure error | - | 9.81 | 5 | 1.96 | - | - |
| Corrected total | - | 346.8 | 19 | - | - | - |
| R² | - | 0.9443 | - | - | - | - |
| Coefficient of variation | - | 2.53 | - | - | - | - |
| Standard deviation | - | 1.22 | - | - | - | - |

$X_1$ = osmotic solution concentration (% w/v); $X_2$ = immersion time (min); $X_3$ = osmotic temperature (°C); DF = degrees of freedom.

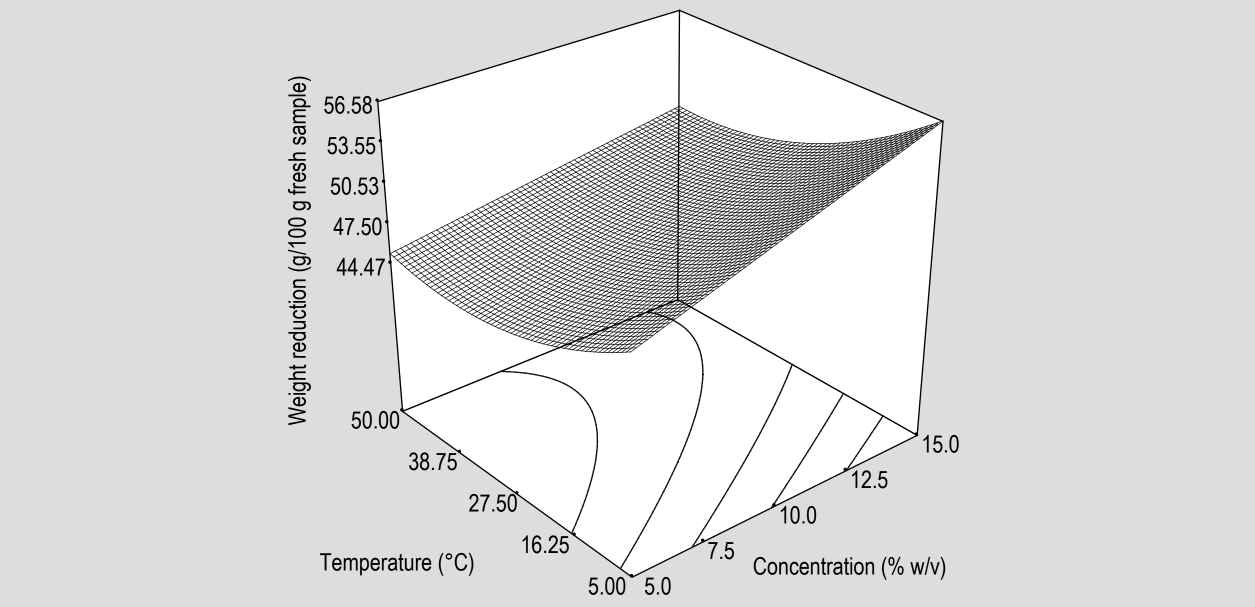

**Figure 4. Effect of osmotic solution temperature and concentration on weight reduction during osmotic dehydration of pumpkin.**

### Effect of variables on final moisture content

The results showed that linear and quadratic terms of all process variables have a positive effect (*P*<0.01) on final moisture content during osmotic dehydration (Table 6). Furthermore, the effect of immersion time on final moisture content was somewhat greater than that of the other factors (F<0.0001). On the other hand, the interaction term $X_1X_2$ has a significant effect, whereas the interactions terms $X_1X_3$ and $X_2X_3$ have a negative effect on weight reduction. Figure 5 also shows that by increasing the immersion time and osmotic solution concentration, the final moisture content decreased. This can be explained by the synergistic effect of binary solutions of sucrose and salt on final

**Table 6. Regression summary and ANOVA table for final moisture content in coded values of process variables.**

| Source | Regression coefficient (βn) | Sum of squares | DF | Mean square | F value | Prob > F |
|---|---|---|---|---|---|---|
| Model | - | 2.02 | 9 | 0.22 | 143.44 | <0.0001 |
| Intercept | +1.65 | - | - | - | - | - |
| $X_1$ | +0.41 | 1.73E-03 | 1 | 1.73E-03 | 1.1 | 0.3181 |
| $X_2$ | -0.031 | 0.56 | 1 | 0.56 | 360.15 | <0.0001 |
| $X_3$ | +0.024 | 0 | 1 | 0 | 0 | 1 |
| $X_1^2$ | -0.031 | 0.052 | 1 | 0.052 | 33.18 | 0.0002 |
| $X_2^2$ | +1.91E-04 | 0.048 | 1 | 0.048 | 30.9 | 0.0002 |
| $X_3^2$ | -4.39E-04 | 0.14 | 1 | 0.14 | 86.79 | <0.0001 |
| $X_1X_2$ | -7.49E-04 | 0.022 | 1 | 0.022 | 13.83 | 0.004 |
| $X_1^2X_2$ | +2.14E-04 | 0.16 | 1 | 0.16 | 105.21 | <0.0001 |
| $X_1X_2^2$ | -1.54E-05 | 0.12 | 1 | 0.12 | 78.79 | <0.0001 |
| Residual | - | 0.016 | 10 | 1.5E-03 | - | - |
| Lack of fit | - | 5.6E-03 | 5 | 1.13E-03 | 0.56 | 0.7292 |
| Pure error | - | 0.01 | 5 | 2.1E-03 | - | - |
| Corrected total | - | 2.04 | 19 | - | - | - |
| R² | - | 0.9923 | - | - | - | - |
| Coefficient of variation | - | 2.99 | - | - | - | - |
| Standard deviation | - | 0.04 | - | - | - | - |

$X_1$ = osmotic solution concentration (% w/v); $X_2$ = immersion time (min); $X_3$ = osmotic temperature (°C); DF = degrees of freedom.

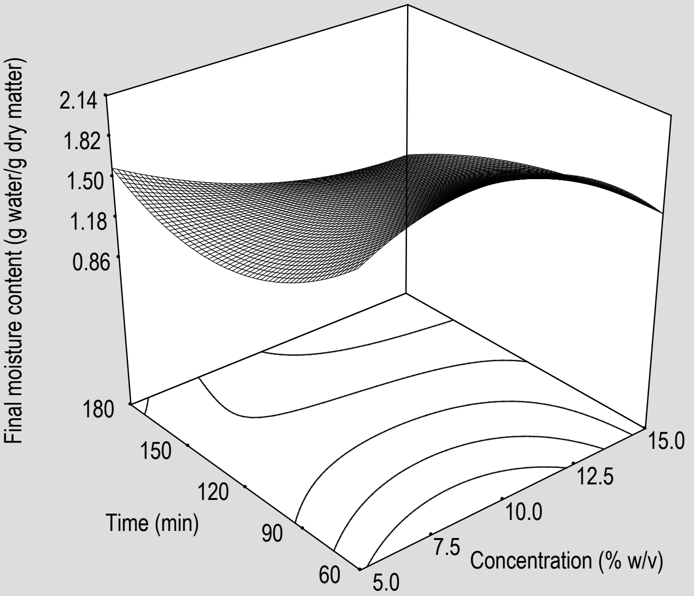

**Figure 5. Effect of osmotic solution concentration and process time on final moisture content during osmotic dehydration of pumpkin**

moisture content. In addition, increasing osmotic solution temperature led to sample swelling and diffusion of more water from the sample (Eren and Kaymak-Ertekin, 2007).

### Optimisation of osmotic dehydration process

Optimum condition for osmotic dehydration of pumpkin was determined to obtain maximum WL and weight reduction and minimum SG. Second order polynomial models obtained in this study were utilised for each response in order to determine the specified optimum conditions. The optimum values obtained by substituting the respective actual values of variables are: temperature = 5 °C, processing time = 180 min and osmotic solution concentration = 50% sucrose + 15% Nacl w/v. At this point, WL, SG, weight reduction and final moisture content was calculated to be 70.7 (g/100 g initial sample), 10.2 (g/100 g initial sample), 59.06 (g/100 g initial sample) and 0.64 (g water/g dry matter), respectively (the best desirability was calculated to be 0.886).

### Equilibrium water loss and solid gain

Equilibrium water loss ($WL_\infty$) and solid gain ($SG_\infty$) values were predicted by fitting the model to experimental data. Figure 6 and 7 show variation of t/WL and t/SG against time at different osmotic solution temperatures and concentrations. In order to modelling, two parameter models developed by Azuara *et al.* (1992) were applied to predict the kinetics of osmotic dehydration of pumpkin and compute the ultimate WL and SG at equilibrium conditions. The slope ($1/WL_\infty$ or $1/SG_\infty$) and intercept ($1/S_1WL_\infty$ or $1/S_2SG_\infty$) values were determined by linear regression of the curve plotted between t/WL and t/SG versus time.

Tables 7 and 8 show the equilibrium WL and SG values as well as the regression coefficient $R^2$ and regression equations in nine combinations of different concentrations and temperatures. In most cases, the regression coefficient was greater than 0.9955 indicating the acceptability of the model proposed by Azuara *et al.* (1992) for the prediction of equilibrium WL and SG of pumpkin during osmotic

**Table 7. The value of water loss (WL) at time ∞ and kinetic constant for water loss ($S_1$) under different dehydration conduction.**

| Type of osmotic solution (% w/v) | Temperature (°C) | $WL_\infty$ (g/100 g fresh sample) | $S_1$ (1/min) | Regression equation[1] | $R^2$ |
|---|---|---|---|---|---|
| 50% sucrose + 5% NaCl | 5 | 66.67 | 0.047093 | $t/WL_j = 0.015t + 0.3185$ | 0.9997 |
| | 25 | 68.49 | 0.043649 | $t/WL_j = 0.0146t + 0.3345$ | 0.9998 |
| | 50 | 71.43 | 0.049156 | $t/WL_j = 0.014t + 0.2848$ | 0.9994 |
| 50% sucrose + 10% NaCl | 5 | 70.92 | 0.052476 | $t/WL_j = 0.0141t + 0.2687$ | 0.9996 |
| | 25 | 76.33 | 0.037952 | $t/WL_j = 0.0131t + 0.3452$ | 0.9987 |
| | 50 | 78.74 | 0.044844 | $t/WL_j = 0.0127t + 0.2832$ | 0.9993 |
| 50% sucrose + 15% NaCl | 5 | 75.18 | 0.062069 | $t/WL_j = 0.0133t + 0.2143$ | 0.9996 |
| | 25 | 82.64 | 0.043795 | $t/WL_j = 0.0121t + 0.2763$ | 0.9989 |
| | 50 | 85.47 | 0.046856 | $t/WL_j = 0.0117t + 0.2497$ | 0.9994 |

[1] t = time.

**Table 8. The value of solid gain (SG) at time ∞ and kinetic constant for solid gains ($S_2$) under different dehydration conduction.**

| Type of osmotic solution (% w/v) | Temperature (°C) | $SG_\infty$ (g/100 g fresh sample) | $S_2$ (1/min) | Regression equation[1] | $R^2$ |
|---|---|---|---|---|---|
| 50% sucrose + 5% NaCl | 5 | 8.4889 | 0.044615 | $t/SG_j = 0.1178t + 2.6404$ | 0.9987 |
| | 25 | 17.152 | 0.020689 | $t/SG_j = 0.0583t + 2.8181$ | 0.9966 |
| | 50 | 21.186 | 0.022902 | $t/SG_j = 0.0472t + 2.061$ | 0.9975 |
| 50% sucrose + 10% NaCl | 5 | 9.5057 | 0.048109 | $t/SG_j = 0.1052t + 2.1867$ | 0.9998 |
| | 25 | 19.084 | 0.025705 | $t/SG_j = 0.0524t + 2.0385$ | 0.9958 |
| | 50 | 25.974 | 0.023667 | $t/SG_j = 0.0385t + 1.6267$ | 0.9974 |
| 50% sucrose + 15% NaCl | 5 | 11.086 | 0.059430 | $t/SG_j = 0.0902t + 1.5178$ | 0.9998 |
| | 25 | 22.371 | 0.025045 | $t/SG_j = 0.0447t + 1.7848$ | 0.9955 |
| | 50 | 32.362 | 0.024508 | $t/SG_j = 0.0309t + 1.2608$ | 0.9957 |

[1] t = time.

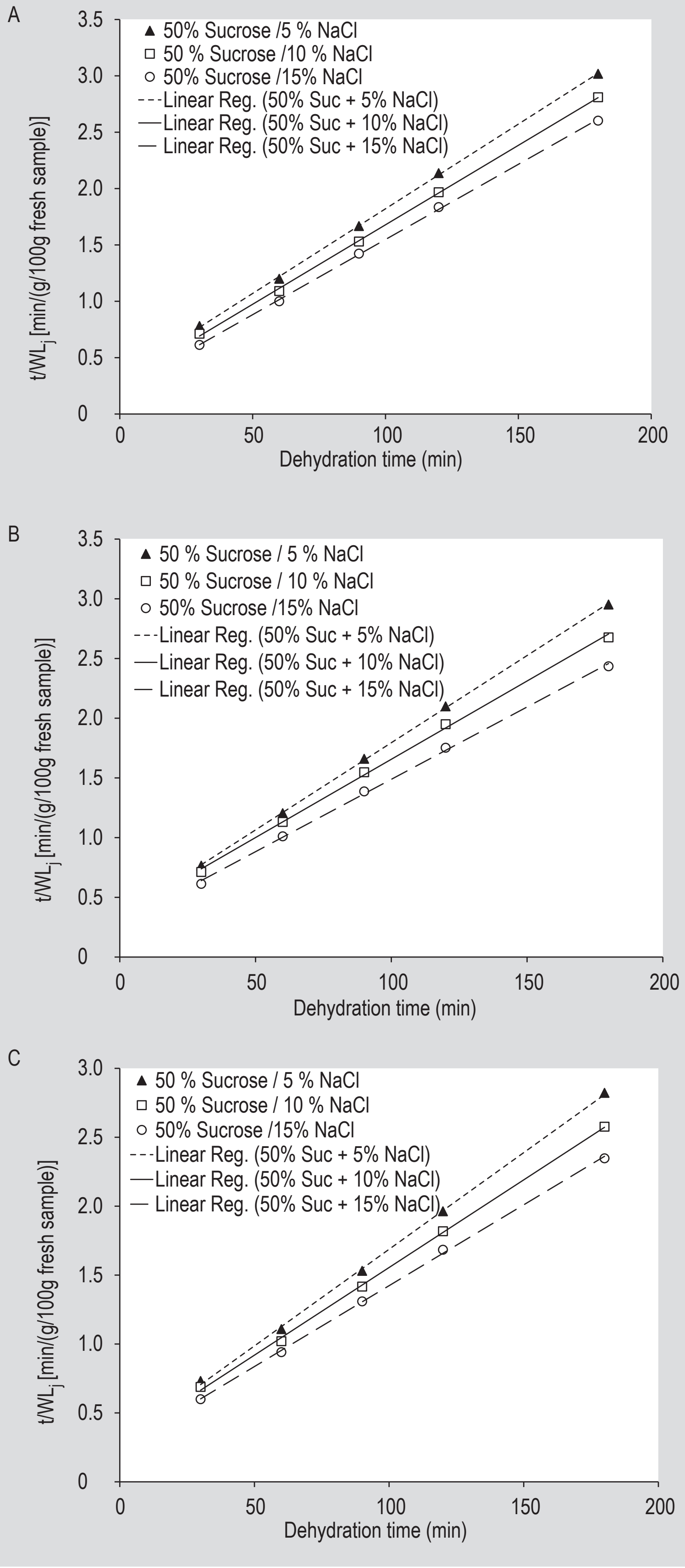

**Figure 6. Variation of t/WL$_j$ versus dehydration time to predict the equilibrium water loss at a temperature of (A) 5 °C, (B) 25 °C and (C) 50 °C (osmotic solution included)**

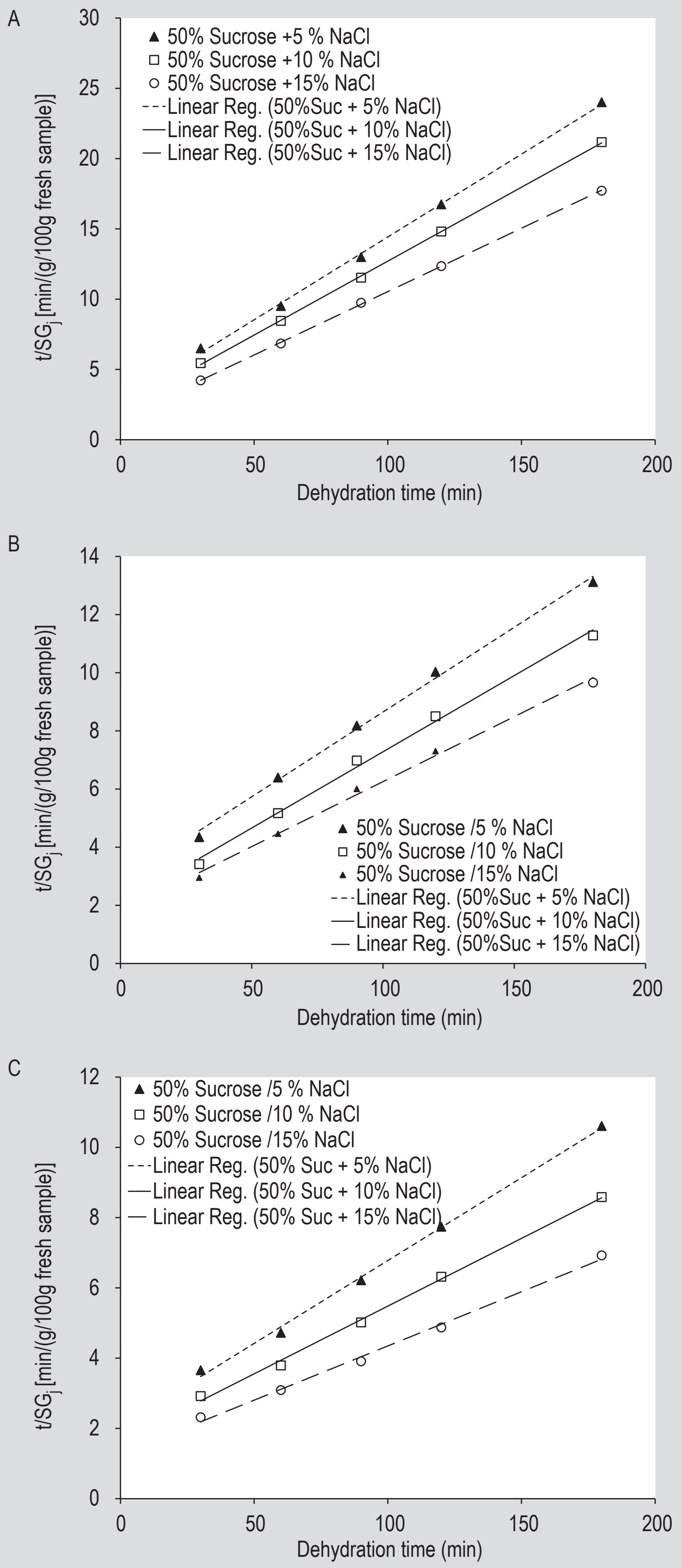

**Figure 7. Variation of t/SG$_j$ versus dehydration time to predict the equilibrium solid gain at a temperature of (A) 5 °C, (B) 25 °C and (C) 50 °C (osmotic solution included)**

dehydration at different temperatures and concentration of osmotic solution.

### Modelling of artificial neural network

In this work, a combination of different layers and neurons with different activation functions were used for modelling perceptron neural network. Neural network consisted one and two hidden layers, 2 to 20 neurons were selected randomly and network power was estimated to predict final moisture content during osmotic process. The obtained result of MLP network with logsig, tanh and tanh-logsig activation function and different topologies are shown in Figure 8. Comparison of obtained result of ANN with different activation function revealed that tanh function (one hidden layer) with 3-14-1 (i.e. network with 3 inputs, 14 neurons per hidden layers and 1 output) neurons in hidden layers were selected as the best configuration to predict final moisture content during mass transfer kinetic of dehydrated pumpkins. Therefore, this network was able to predict the final moisture content with a mean relative error value equal 0.00128. As well, $R^2$ value for this factor was achieved 0.998.

Model sensitivity diagram of predicted parameter by MLP network with tanh activation function vs. experimental parameter for the best topology (i.e. structure of 3-14-1) showed that data were randomly located around the regression line. This could be a reason for good performance of the neural networks to predict the final moisture content of pumpkin during osmotic dehydration kinetic (Figure 9).

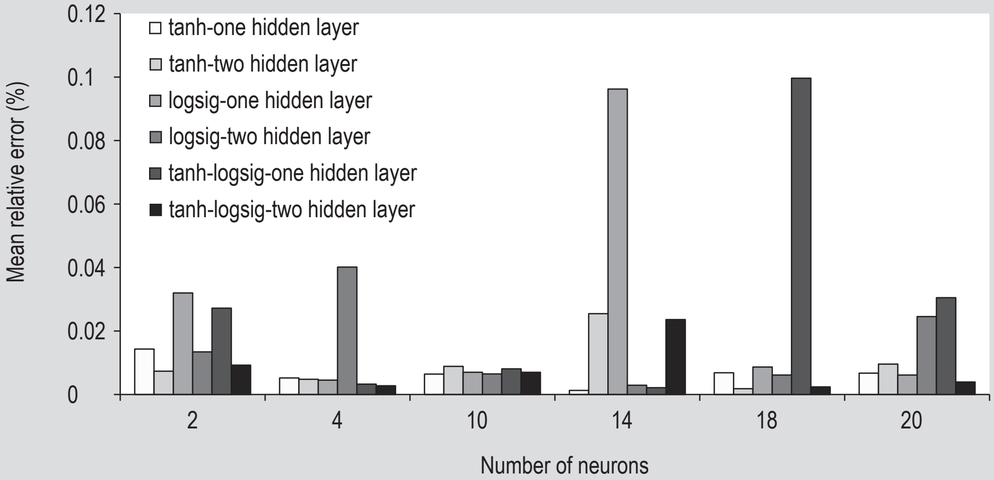

**Figure 8. The mean relative error values obtained from multilayer perceptron network to predict the final moisture content.**

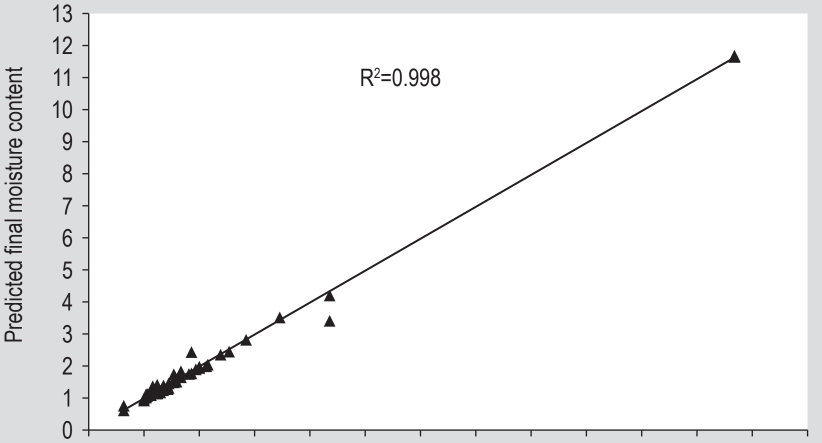

**Figure 9. Comparison of experimental and predicted final moisture content obtained by the best activation function of artificial neural network (tanh).**

In network optimisation (i.e. configuration of 3-14-1 and tanh activation function), the matrices of weights (A matrix of 12×14 between input and first hidden layer and B matrix of 14×1 between first hidden layer and output layer) and bias values (input bias matrix of 1×14 for first hidden layer (i.e. matrix of $B_{input}$) and output bias matrix of 1×1 for output layer (i.e. matrix of $B_{output}$) were obtained as shown in Figure 10.

## 4. Conclusions

RSM was used to determine the optimum operating conditions that produce maximum WL and weight reduction and minimum SG and final moisture content in osmotic dehydration of pumpkin. Analysis of variance has shown that the effect of all process variables including temperature, immersion time and osmotic solution concentration were significant. Second order polynomial models were achieved for predicting WL, SG, weight reduction and final moisture content. $R^2$ values for WL, SG, weight reduction and final moisture content were computed 0.9644, 0.9826, 0.9443 and 0.9923 respectively. The optimum conditions were found to be: temperature = 5 °C, processing time = 180 min and osmotic solution concentration = 15% salt + 50% sucrose w/v. At this optimum condition, WL, SG, weight reduction and final moisture content were found to be: 70.7 g/100 g initial sample, 10.2 g/100 g initial sample, 59.06 g/100 g initial sample and 0.64 g water/g dry matter, respectively. On the other hand, in this study, an ANN trained by back propagation algorithms was developed to feasibly predict final moisture content based on the 3 input variables. Different factors including number of neurons (2 to 20) and type of activation function in hidden and output layers (logsig, tanh and tanh-logsig) were used in order to find the best topology of ANN for monitoring the final moisture content during dehydration kinetic.

$$A=\begin{bmatrix}
-0.205 & 0.412 & -0.604 & -0.618 & -0.922 & 0.588 & 0.813 & -0.115 & -0.890 & 0.269 & -0.231 & 0.158 & -0.577 & -0.417 \\
-0.239 & 0.371 & 0.165 & 0.108 & -0.091 & 0.008 & -0.102 & -0.356 & -0.050 & -0.339 & -0.283 & -0.050 & 0.256 & 0.228 \\
0.294 & 0.299 & -0.004 & 0.440 & 0.700 & -0.046 & -0.106 & -0.108 & -0.303 & 0.129 & -0.390 & 0.002 & 0.122 & 0.202 \\
0.260 & -0.052 & 0.471 & 0.507 & 0.229 & -0.079 & -0.182 & -0.196 & -0.222 & -0.344 & -0.080 & -0.353 & -0.222 & -0.011 \\
0.200 & -0.369 & -0.133 & 0.186 & 0.293 & -0.376 & 0.375 & -0.308 & 0.360 & -0.033 & 0.198 & 0.417 & 0.261 & -0.004 \\
0.337 & 0.284 & 0.183 & -0.041 & -0.189 & -0.525 & -0.215 & -0.131 & 0.200 & -0.450 & 0.020 & -0.250 & 0.536 & 0.246 \\
0.030 & -0.382 & 0.372 & 0.136 & 0.039 & 0.099 & 0.325 & -0.309 & -0.265 & -0.300 & -0.080 & -0.060 & 0.381 & 0.060 \\
0.313 & 0.034 & -0.054 & 0.585 & 0.474 & 0.135 & 0.320 & 0.147 & -0.326 & -0.090 & -0.157 & 0.498 & -0.010 & -0.106 \\
-0.189 & 0.410 & 0.135 & 0.188 & 0.422 & -0.295 & -0.285 & -0.072 & -0.097 & 0.272 & -0.480 & 0.378 & -0.107 & -0.215 \\
0.381 & 0.370 & 0.187 & 0.201 & -0.283 & -0.447 & 0.260 & 0.242 & 0.070 & 0.128 & 0.008 & 0.470 & -0.154 & 0.483 \\
-0.370 & -0.412 & 0.176 & 0.238 & 0.382 & 0.139 & -0.258 & 0.090 & -0.159 & 0.489 & -0.211 & 0.180 & -0.150 & 0.367 \\
0.375 & 0.164 & -0.490 & -0.160 & 0.076 & -0.351 & 0.333 & 0.301 & -0.157 & 0.137 & -0.169 & 0.445 & 0.394 & 0.280
\end{bmatrix}$$

$$B=\begin{bmatrix}
-0.307 \\ 0.445 \\ -0.599 \\ -0.773 \\ -0.826 \\ 0.681 \\ 0.660 \\ -0.266 \\ -0.834 \\ 0.127 \\ -0.192 \\ 0.379 \\ -0.751 \\ -0.314
\end{bmatrix}$$

$$\text{Bias}_{\text{input}}=\begin{bmatrix}-0.054 & 0.297 & 0.029 & -0.166 & -0.257 & -0.077 & -0.09 & 0.075 & 0.488 & -0.238 & 0.492 & 0.33 & -0.21 & -0.383\end{bmatrix}$$

$$\text{Bias}_{\text{output}}=\begin{bmatrix}-0.447\end{bmatrix}$$

**Figure 10. A matrix of 12×14 between input and first hidden layer; B matrix of 14×1 between first hidden layer and output layer; input bias matrix of 1×14 for first hidden layer ($\text{Bias}_{\text{input}}$); and output bias matrix of 1×1 for output layer ($\text{Bias}_{\text{output}}$).**

Results indicated that, ANN with tanh activation function based on 14 neurons in the first hidden layer was able to estimate the final moisture content with a high $R^2$ value (0.998). Comparison between ANN and RSM modelling showed that ANN (a novel and non-destructive method) has a higher ability to predict final moisture content ($R^2$ for RSM was 0.992; Table 6) than RSM modelling.

## References

Aghajani, N., Kashaninejad, M., Dehghani, A.A. and Daraei Garmakhany, A., 2012. Comparison between artificial neural networks and mathematical models for moisture ratio estimation in two varieties of green malt. Quality Assurance and Safety of Crops and Foods 4: 93-101.

Agarry, S.E., Yusuf, R.O. and Owabor, C.N., 2008. Mass transfer in osmotic dehydration of potato: a mathematical model approach. Journal of Engineering and Applied Sciences 3: 190-198.

Association of Official Analytical Chemists (AOAC), 1990. AOAC official method 931.04. Moisture in cacao products. AOAC, Washington, DC, USA.

Azuara, E., Cortes, R., Garcia, H.S. and Beristain, C.I., 1992. Kinetic model for osmotic dehydration and its relationship with Fick's second law. International Journal of Food Science and Technology 27: 409-418.

Chang, M.J., Han, M.R. and Kim, M.H., 2003. Effects of salt addition in sugar based osmotic dehydration on mass transfer and browning reaction of green pumpkin. Journal of Agricultural Chemistry and Biotechnology 46: 92-96.

Chenlo, F., Moreira, R., Fernandez-Herrero, C. and Vazquez, G., 2006. Mass transfer during osmotic dehydration of chestnut using sodium chloride solutions. Journal of Food Engineering 73: 164-173.

De Souza Silva, K., Cássia Caetano, L., Castilho Garcia, C., Telis Romero, J., Barbosa Santos, A., Aparecida Mauro, M. and Ismail, O., 2011. Osmotic dehydration process for low temperature blanched pumpkin. Journal of Food Engineering 105: 56-64.

Eren, I. and Kaymak-Ertekin, F., 2007. Optimization of osmotic dehydration of potato using response surface methodology. Journal of Food Engineering 79: 344-352.

Fernandes, F.A.N., Gallão, M.I. and Rodrigues, S., 2008. Effect of osmotic dehydration and ultrasound pre-treatment on cell structure: melon dehydration. LWT-Food Science and Technology 41: 604-610.

Garcia-Noguera, J., Oliveira, F.I.P., Gallão, M.I., Weller, C.L., Rodrigues, S. and Fernandes, F.A.N., 2010. Ultrasound-assisted osmotic dehydration of strawberries: effect of pretreatment time and ultrasonic frequency. Journal of Drying Technology 28: 294-303.

Hawkes, J. and Flink, J.M., 1978. Osmotic dehydration of fruit slices prior to freeze dehydration. Journal of Food Processing and Preservation 2: 265-284.

Ispir, A. and Togrul, I.T., 2009. Osmotic dehydration of apricot: kinetics and the effect of process parameters. Journal of Chemical Engineering Research and Design 87: 166-180.

Kashiri, M., Daraei Garmakhany, A. and Deghani, A.A., 2012. Modeling of sorghum soaking using artificial neural networks (MLP). Quality Assurance and Safety of Crops and Foods 4: 179-184.

Kaymak-Ertekin, F. and Sultanoglu, M., 2000. Modelling of mass transfer during osmotic dehydration of apples. Journal of Food Engineering 46: 243-250.

Kowalska, H. and Lenart, A., 2001. Mass exchange during osmotic pretreatment of vegetables. Journal of Food Engineering 49: 137-140.

Kowalska, H., Lenart, A. and Leszczyk, D., 2008. The effect of blanching and freezing on osmotic dehydration of pumpkin. Journal of Food Engineering 86: 30-38.

Khuri, A.I. and Cornell, J.A., 1987. Response surfaces design and analysis. Marcel Dekker, Inc., New York, NY, USA.

Lenart, A. and Flink, J.M., 1984. Osmotic concentration of potato: I. criteria for the end point of the osmosis process. International Journal of Food Science and Technology 19: 45-63.

Lenart, A., Lewicki, P. and Karandys, S., 1993. Kinetics of osmotic dehydration of pumpkin. In: Proceedings of the 5th seminar Properties of water in foods, Warschau, Poland, pp. 127-143.

Lertworasirikul, S. and Saetan, S., 2010. Artificial neural network modeling of mass transfer during osmotic dehydration of kaffir lime peel. Journal of Food Engineering 98: 214-223.

Mohebbi, M., Shahidi, F., Fathi, M., Ehtiati, A. and Noshad, M., 2010. Prediction of moisture content in pre-osmosed and ultrasounded dried banana using genetic algorithm and neural network. Journal of Food and Bioproduct Processing 89: 362-366.

Mousavi, M. and Javan, S., 2009. Modeling and simulation of apple drying, using artificial neural network and neuro-taguchi's method. Journal of Agricultural Science and Technology 11: 559-571.

Shafafi Zenoozian, M. and Devahastin, S., 2009. Application of wavelet transform coupled with artificial neural network for predicting physicochemical properties of osmotically dehydrated pumpkin. Journal of Food Engineering 90: 219-227.

Singh, N.J. and Pandey, R.K., 2011. Neural network approaches for prediction of drying kinetics during drying of sweet potato. Agricultural Engineering International: CIGR Journal 13: 1-7.

Singh, B., Panesar, P.S., Nanda, V. and Kennedy, J.F., 2010. Optimisation of osmotic dehydration process of carrot cubes in mixtures of sucrose and sodium chloride solutions. Journal of Food Chemistry 123: 590-600.

Togrul, I. and Ispir, A., 2007. Effect on effective diffusion coefficients and investigation of shrinkage during osmotic dehydration of apricot. Journal of Energy Conversion and Management 48: 2611-2621.