Possibility of using neural networks for moisture ratio prediction in dried potatoes by means of different drying methods and evaluating physicochemical properties

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Abstract: Potato cubes were dried by different drying methods. After the end of drying process, the experimental data were first fitted to the four well-known drying models. The results indicated that the logarithmic and page models performed better compared with the other models. Also, in this study neural networks were used in order to possibly predict dried potato moisture ratio (*y*), based on three input variables of drying time, drying temperature and different methods. The results revealed that, *logsig* function based on 10 neurons in the first hidden layer could perform as the best goodness configuration for predicting the moisture ratio. The comparison of the obtained results of ANNs and classical modeling indicated that, the neural networks have a higher capability for predicting moisture ratio (R^2 values 0.9972 and 0.996, respectively) compared with classical modeling. Furthermore, the physicochemical properties of dried potato such as shrinkage, starch gelatinization temperature, color change, etc. were also determined.

Keywords: Monolayer drying, potato slice, Artificial Neural Network, image processing

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1 Introduction

Potato (*Solanum teberoasum*) is a tetraploid plant of the family *Solanum Genus* and *solanaceae*. Based on FAO statistics, Iran produced about 4.05 million tons of potato in 2010 (FAO, 2010). Nowadays, different drying methods are used for producing dried products. Among them, one can mention convective hot air drying, microwave drying, freeze drying, ultrasound drying, super critical fluid drying, infra red drying, combined drying etc. Some of the main factors in choosing drying method could be the costs of the machinery, transport costs, maintenance, daily production volume, drying rate and the product quality. The main disadvantages of hot air drying of foods are low energy efficiency and long drying time. Because of the low thermal conductivity of food materials, heat transfer to the inner sections of foods during conventional heating is limited. Overcoming this problem and preventing significant quality loss and thus achieving fast and effective thermal processing have reflected in the increased utilization of microwaves for food drying (Wang and Xi, 2005). Microwave drying of foods and agricultural products take advantage of the specific responses of the food substances to heating microwave. Some of the advantages of the microwave heating in the drying of foods and agricultural products

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over the conventional drying methods are fast and volumetric heating, higher drying rate, shorter drying time, quality of the product better, reduced energy consumption and cost savings (Mujumdar, 2000). Nowadays, neural networks have an important role as a powerful tool in predicting process parameters. Many studies have been carried out in the field of ANNs. Momenzadeh et al. (2011) predicted drying time of corn shell during drying by concurrent microwave-fluidized bed dryer via ANNs. ANNs were utilized to predict moisture ratio of dried potato slices by different drying methods in this project. As to high potato wastage in post harvest and storage steps, production of dried products is necessary to increase its shelf life. Therefore, the aim of this study was to compare different methods in potato drying and selecting the best production method. Also the moisture ratio of dried potato was compared through classic modeling and ANNs as an important parameter in the drying process.

2 Materials and methods

2.1 Raw material preparation

First, fresh potato (Baraka cultivar) was provided from Mojen village near Shahrood (A city in North East of Iran, 2196 m above mean sea level (AMSL)). Samples were preserved to the end of the experiments in cold storage at 10°C (24 h before processing were exited from storage and preserved at room temperature (20°C). Initially, potato samples were sorted with regard to appearance and size and peeled with knife. Then samples were washed and sliced by manual potato dicer (Vidalia-chap wizard, model K6096, made in China), cubed dices with 10×10×10 mm dimension. Fresh potatoes had 19.5% dry matter, specific weight: 1.08±1 g cm-3 and approximately weight: 80-100 g. The initial moisture content was determined through direct heating via a laboratory oven (Memmert, model UNE 400 PA, Scheabach, Germany) at 105°C for 48 h according to AOAC method 931.04. Average initial moisture content of potato was estimated as 80.5% (wet basis).

2.2 Drying methods and the required equipments

In order to do the drying process, samples were first blanched as pre-treatment. The rationale behind this pre-processing was destroying poly phenol oxidase in potatoes in order to reduce color changing rates during processing. Samples were then submerged in boiling water at 95°C for 5 min. (Sotome et al., 2009). Sample surfaces were washed with cold water and surface humid was omitted with filter paper after blanching in order to remove starch and secreted reducing sugar from cube surfaces and reduce the caused problems during drying (Reyes et al., 2007). Then samples were rinsed in sulfur solution (0.01 g per 1000^{cc}) and citric acid (0.2 g per 1000^{cc} during 20 min). Using acid ascorbic solution was due to produced ortho quinine by phenolase to ortho diphenol. Also using sodium bisulfate can directly influence poly phenol oxidase (phenolase) enzyme structure and thus inactivating enzymes (Kiattisak et al., 1999). Samples are processed in different conditions after blanching and chemical pre-processes. So, three drying methods were used including hot air drying (AD), Microwave drying (MW) and Combinative hot air drying-Microwave drying (AD-MW). Laboratory Dryer (Tak Azmaco, Made in Iran) was used in 65°C and 70°C to convective hot air drying, Butan microwave dryer (CE245G model, made in Iran), was used for microwave drying. This model has got 1,500 W power with the maximum output power is 900 W and 34 L capacity which is equipped with a fan for air convection within the microwave chamber. Drying continued to reach moisture content equal to 11% (wet basis).

2.3 Modeling of drying kinetic process

Monolayer drying models of experimental data for potato slices were expressed in the form of moisture ratio of samples during monolayer drying and it was displayed as Equation (1).

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{1}$$

In these equations, MR, M, M_0 and M_e, are the moisture ratio, moisture content at any time, initial moisture content and equilibrium moisture content, respectively. Drying runs were done in triplicates. Functions and mathematical models were simulated by software Sigma Plot Ver. 11. The drying curves obtained were fitted with three different moisture ratio models as is shown in Table 1 (Goyal et al., 2008).

Table 1 Drying kinetic models

Equation	Name
$MR = \exp(-kt)$	Newton
$MR = a\exp(-kt)$	Henderson and Pabis
$MR = \exp(-kt^n)$	Page
$MR = a\exp(-kt) + C$	Logarithmic

The coefficient of determination (R^2) was one of the main criteria for selecting the best equation. In addition to the coefficient of determination, the goodness of fit was determined by various statistical parameters such as reduced chi square (χ^2), mean relative deviation modulus P (%) and root mean square error $RMSE$. For quality fit, R^2 value should be higher and χ^2, P (%) and $RMSE$ values should be lower (Goyal et al., 2008). The above parameters can be calculated as Equation (2), Equation (3) and Equation (4):

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{e,i} - MR_{p,i})^2}{N - z} \tag{2}$$

$$P(\%) = \frac{100}{N}\sum_{i=1}^{N}\left|MR_{p,i} - MR_{e,i}\right| \tag{3}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{p,i} - MR_{e,i})\right]^{\frac{1}{2}} \tag{4}$$

where, $MR_{e,i}$ is experimental moisture ratio; $MR_{p,i}$ is predicted moisture ratio; N is the number of experimental data and z, the number of model parameters.

2.4 Evaluating physicochemical properties of dried product

2.4.1 Shrinkage

Three samples were chosen for each shrinkage measurement. The percentage of shrinkage was computed as shown in Equation (5).

$$Shrinkage = \frac{V_i - V_f}{V_i} \tag{5}$$

In this equation, V_i is the volume of fresh potatoes (cm^3) and V_f, the volume of potatoes after drying (cm^3). The sample volume was determined by toluene displacement. The mass of the sample displaced in toluene was measured via a digital balance (Jewelry, AND, model FX-CT SERIES, FX-300 CT, Japan). The volume of the sample was calculated according to the Equation (6) (Sahin and Sumnu, 2006).

$$Volume = \frac{Mass\ of\ displaced\ toluene\,(\mathrm{g})}{Density\ of\ toluene\,(\mathrm{g/cm^3})} \tag{6}$$

2.4.2 Rehydration ratio

Rehydration test was performed at 25°C in distilled water for 420 min (7 h). About 5±0.5 g dried products were placed in glass beakers containing water with the ratio of 1:20 (w/w). After the specified time, the samples were taken out and blotted with tissue paper to remove water on the surface. The weights of dried and rehydrated samples were measured with an electronic digital balance having a sensitivity of ±0.01g. The rehydration ratio (RR) was calculated by the Equation (7) (Huang et al., 2011).

$$Rahydration\,ratio = \frac{w_r - w_d}{w_d} \tag{7}$$

In equation above, W_r is the sample mass after rehydration process and W_d is the mass of dried sample.

2.4.3 Specific gravity and porosity

At first, evaluated cubes volume was determined in order to decide on specific gravity calculation of the dried samples. Sample volume was tested through represented method in shrinkage evaluation (section 2.4.1). Then specific gravity of dried cubes was determined by the Equation (8).

$$SG = \frac{\rho_{sample}}{\rho_{ref}} \tag{8}$$

where, ρ_{sample} is the sample density (g cm^{-3} and the ρ_{ref}, refers to the reference density (g cm^{-3}. Reference solvent was water for specific gravity determination. It is necessary to note that water density and sample should be determined in specific pre-defined temperature (Heldman and Lund, 2007). Graphical software Image J. was used to determine potato porosity. The analyzing procedures in this software involved comparing the two phases (pore and solid section) in the prepared image. At first, sample cross surface was imaged in standard condition for measuring porosity. In order to do this test, some potato cubes were randomly selected and their cross surface was cut with knives. Necessary devices were digital camera (Panasonic, Model NV-GS57GC, 5 mega pixels, Japan) and wooden box internal walls of which were covered with black color (to prevent light reflection and prepare image with high quality). Florescent lamp

(20 W each, length of 60 cm; Pars Shahab Co., Tehran, Iran) was used to provide the required light for imaging. Then, images were transferred to the software and subsequently potato cube images were analyzed for porosity measurements (Sahin and Sumnu, 2006) (Figure 1).

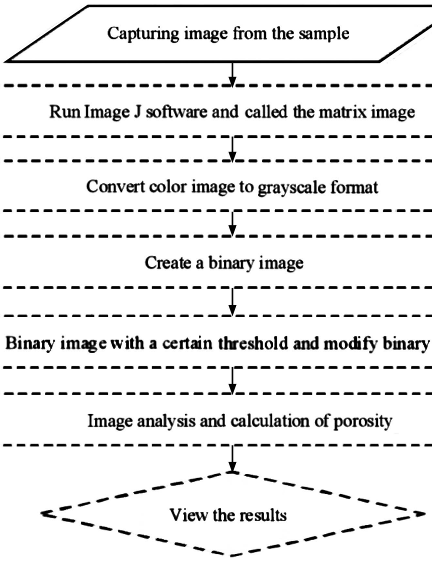

Figure 1 Flow chart of image processing using Image J software for porosity analysis

2.4.4 Color assessment

Potato cubes color was measured by HunterLab set (HunterLab, Model Color flex, made in USA). For color determination, at first the device was calibrated with a white tile. In this set, sample color was measured according to three parameters L, a and b. In this colorimeter system, L parameter measured lightness in range 0 (black)-100 (white). Also two parameters [a] and [b] represented Green-red and blue-yellow that positioned in the range of -120 (green) to +120 (red) and -120 (blue) to +120 (yellow), respectively. In order to operate the colorimeter, 10 potato cubes were randomly selected and color of each sample was measured randomly in three points and mean values of L, [a] and [b] parameters were represented by monitoring (Sahin and Sumnu, 2006). Finally, overall changes of samples color were calculated by Equation (9).

$$\Delta E = \sqrt{(L-L_o)^2+(a-a_o)^2+(b-b_o)^2} \tag{9}$$

In this equation, L_o, a_o and b_o were the L, a, and b values of the reference sample before drying process. Furthermore, Hue angle and Chroma values for potato slices during drying were calculated by Equation (10) and Equation (11) below.

$$Hue = [\tan^{-1}(b/a)] \tag{10}$$

$$Chroma = \sqrt{(a^2+b^2)} \tag{11}$$

2.4.5 Ascorbic acid content measurement

The vitamin C content was determined according to AOAC method 967.12 (AOAC, 2007). For determining the Vitamin C, the researcher used the indicator dye 2, 6-dichloroindophenol in a titration method. Ascorbic acid reduces the indicator dye to a colorless solution. The titer of the dye can be determined using a standard ascorbic acid solution. Food samples in solution then can be titrated with the dye, and the volume for the titration is used to calculate the ascorbic acid content.

2.4.6 Determining starch gelatinization temperature and starch content

Starch content was determined by the polarimetric method (AOAC, 1975). In this method, starch content was determined on the basis of the polarization angle. The following equation was used to determinate starch content of dried potato.

$$C = \frac{100A}{L.[\alpha]} \times \frac{100}{w} \tag{12}$$

where, C is starch content (%); A is angle of specific rotation (°A); L is cell length (dm); W is mass of sample (g) and α is degree of specific rotation (α=195.2).

In order to determinate starch gelatinization temperature, at first potato cubes were prepared by means of different drying methods then separately milled (Moulinex, Model depose, made in French). A beaker containing 10% slurry of potato cube powder was inserted in laboratory water bath (Memmert, Model WB14, made in Germany). The sample was concurrently mixed and the mixture temperature was adjusted with thermometer (Model CE0197, made in china). The temperature at which slurry experiences liquefaction is the starch gelatinization temperature. Here, the temperature having the highest liquefaction was reported as gelatinization temperature range.

2.5 Artificial Neural Network (ANN)

An artificial neural network is composed of simple processing elements called neurons that are connected to each other by weights. The neuron is grouped into distinct layers and interconnected according to a given architecture (Mousavi and Javan, 2009). A multilayer perception (MLP) network is one of the most popular and successful neural network architectures, suited to a wide range of engineering applications involving drying (Equation (13)).

$$y_j = \sum_{i=1}^{n} f(w_{ij}x_i) + b_j \tag{13}$$

where, y_j is the net input of each neuron in the hidden and output layers; x_i the input; n the number of inputs to the neuron; w_{ij} the weight of the connection between neuron i and neuron j and b_j the bias associated with j^{th} neuron (Mohebbi et al., 2011). Each neuron consists of a transfer function expressing its internal activation level. Output from a neuron is determined by transforming its input using a suitable transforming function. As it can be seen, Figure 2 shows schematic structure of perceptron neural network.

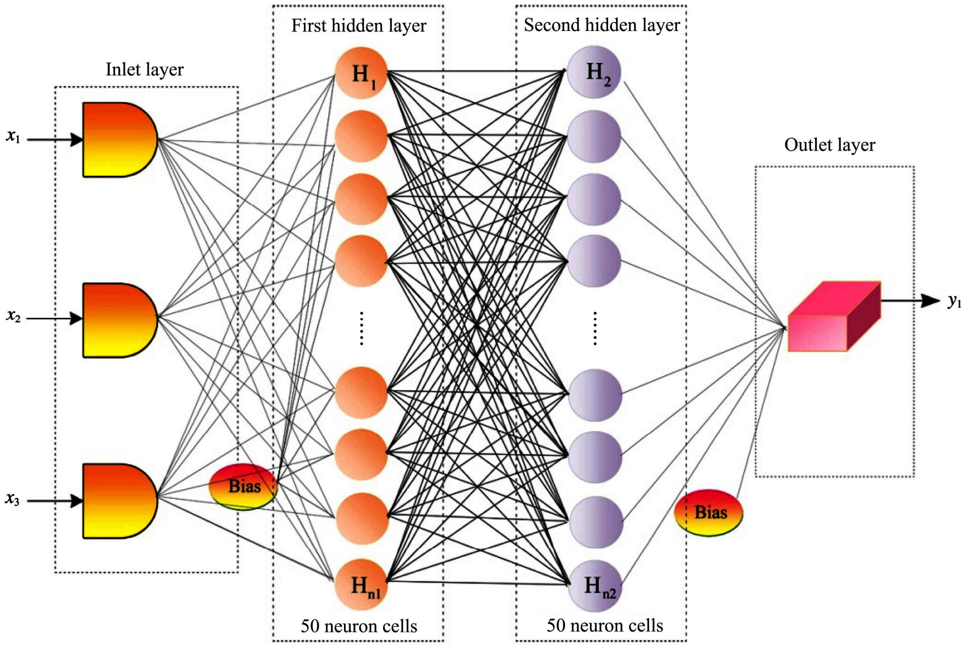

Figure 2 Schematic structure of perceptron neural network.

In this network, the input layer consists of 3 neurons (Drying time (x_1), drying temperature (x_2) and drying methods (x_3) and the output layer contains one neuron (moisture ratio (y)). The back propagation algorithm was used in training ANN model. This algorithm uses the supervised training technique where the network weights and biases are initialized randomly at the beginning of the training phase (Singh and Pandey, 2011). In order to optimize ANN, different factors including hidden layer number, neuron number per hidden layer, type of activation function in hidden and output layers, learning rate and momentum coefficients must be evaluated. In this work, Number of 1-2 hidden layers with 2-20 neurons per hidden layer, learning rate of=0.4, momentum coefficient of=0.9 and activation functions of sigmoid logarithms and hyperbolic tangent in each hidden and output layer were used in order to find the best topology. In order to go for network modeling, data were randomly divided into two groups, 70% used for training and the remaining 30% for testing the network. Data modeling was accomplished using SPSS statistical software version 19 (2011). So, the best network arrangements were used using two criteria of determination coefficient (R^2) and mean relative error (MRE), respectively (Equation (14) and Equation (15)).

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N} (P_{ANN,i} - P_{\exp,i})^2}{\sum_{i=1}^{N} (\overline{P}_{ANN,i} - P_{ANN,i})^2} \right] \tag{14}$$

$$MRE = \left(\frac{1}{N}\sum_{i=1}^{N} \frac{\left|P_{ANN,i} - P_{\exp,i}\right|}{P_{\exp,i}}\right) \times 100 \tag{15}$$

where, P_{ANN} is the predicted ANN output parameter; P_{exp}, experimental data and N, the number of observations.

2.6 Data analysis

Statistical data analyses were carried out through analysis of variance (ANOVA). The Duncan's multi range test was used to establish the multiple comparisons of mean values. Mean values were considered at 95% significance level. A statistical program SAS version 9.1.3 (2004) was used to perform all statistical calculations.

3 Results and discussion

3.1 Drying kinetics of potato slices

In this project, potato monolayer drying was processed with different drying methods. The obtained results for potato thin layer modeling have been represented in Table 2 and Table 3. Four mathematical models (Newtonian, page, Henderson and logarithmic) were used for modeling thin layer drying. Different potato drying methods were fitted by different models. Regression coefficient Index was 0.6577-0.9967; chi-square, 0.0009-0.044; RMSE was 0.0000043-1.43 and P (%) 1.99-16.8. The results of the best fitted model have been represented in different processes with drying time to final moisture content in Table 4. The results revealed that logarithmic model was a well-designed model for AD 65°C, AD 70°C and MW drying methods; page model, was the goodness fitted model for MW-AD 65°C drying methods as well as MW-AD 70°C ones. These models could successfully evaluate drying curve of potato cubes with higher regression coefficients equal to 0.9664.

Table 2 Obtained results of mathematical modeling of potato cube at different drying methods

Drying methods	Models	R^2	χ^2	*RMSE*	*P*/%
AD-65 $^{\circ}$C	Newton	0.9869	0.0029	0.1352	3.86
	Henderson and Pabis	0.9941	0.0014	0.0663	2.85
	Page	0.9917	0.0020	0.1181	3.42
	Logarithmic	0.9948	0.0013	1.4392	2.26
AD-70 $^{\circ}$C	Newton	0.9907	0.0022	0.1363	3.73
	Henderson and Pabis	0.9941	0.0015	0.0873	3.25
	Page	0.9913	0.0022	0.1289	3.75
	Logarithmic	0.9967	0.0009	5.9E-06	1.99
MW	Newton	0.9584	0.0052	0.1902	4.45
	Henderson and Pabis	0.9590	0.0054	0.1938	4.39
	Page	0.9681	0.0042	0.0891	4.33
	Logarithmic	0.9767	0.0032	1.3E-05	4.57
MW-AD 65 $^{\circ}$C	Newton	0.6577	0.0440	0.1903	16.8
	Henderson and Pabis	0.9010	0.0154	0.0597	9.02
	Page	0.9664	0.0054	0.0486	6.02
	Logarithmic	0.9050	0.0156	4.3E-06	7.98
MW-AD 70 $^{\circ}$C	Newton	0.8421	0.0213	0.2830	10.2
	Henderson and Pabis	0.8739	0.0182	0.1140	9.49
	Page	0.9772	0.0035	0.0314	4.35
	Logarithmic	0.9542	0.0073	6.3E-06	5.85

Table 3 Kinetic parameters of applied models at potato drying via different methods

Drying methods	Models	*k*/min^{-1}	*n*	*a*	*c*
AD-65 $^{\circ}$C	Newton	0.00452	-	-	-
	Henderson and Pabis	0.00365	-	0.9169	-
	Page	0.01108	0.8167	-	-
	Logarithmic	0.00336	-	0.9416	-0.0320
AD-70 $^{\circ}$C	Newton	0.00357	-	-	-
	Henderson and Pabis	0.00310	-	0.9456	-
	Page	0.00502	0.9330	-	-
	Logarithmic	0.00244	-	1.0151	-0.0895
MW	Newton	0.23399	-	-	-
	Henderson and Pabis	0.22413	-	0.9661	-
	Page	0.53097	0.3800	-	-
	Logarithmic	0.25802	-	0.9234	0.0565
MW-AD 65 $^{\circ}$C	Newton	0.02261	-	-	-
	Henderson and Pabis	0.00851	-	0.7035	-
	Page	0.23935	0.3679	-	-
	Logarithmic	0.13992	-	0.7418	0.2507
MW-AD 70 $^{\circ}$C	Newton	0.13635	-	-	-
	Henderson and Pabis	0.01683	-	0.6354	-
	Page	0.37098	0.3471	-	-
	Logarithmic	0.18293	-	0.8122	0.1591

Table 4 Archived results of the best model for each drying methods with k value

k/min^{-1}	Selected model	Drying methods
0.00336	Logarithmic	AD-65 $^{\circ}$C
0.00244	Logarithmic	AD-70 $^{\circ}$C
0.25802	Logarithmic	MW
0.23935	Page	MW-AD 65 $^{\circ}$C
0.37098	Page	MW-AD 70 $^{\circ}$C

Note: AD, Air drying and MW, Microwave drying.

Figure 3 represents the variation moisture ratio vs. drying time in different process conditions. As observed in Figure 3, drying curve in microwave processing has got a sharp gradient compared with convective hot air drying. This case is due to high rate of drying with microwave compared with other methods. In hot air drying, at first moisture exits from the sample surface and water is transferred to sample surface but, in microwave drying bulk heat production leads to an increase in internal steam pressure. This phenomenon causes water streaming to sample surface and leads to an increase in drying rate (Paul Singh and Heldman, 2009). Overall bulk heating mechanism of microwave makes the heating process in microwave faster than traditional methods such as convection or conduction. Furthermore, in processing method by microwave, heating is produced within the sample, whereas in ordinary methods heat transfer is managed from outer layer of the product through conduction or convection. A comparison of different methods for potato cubes confirmed the drying rate as MW-AD 70°C >MW-AD 65°C >MW>AD 70°C >AD 65°C, respectively. This case has been clearly shown in Figure 3.

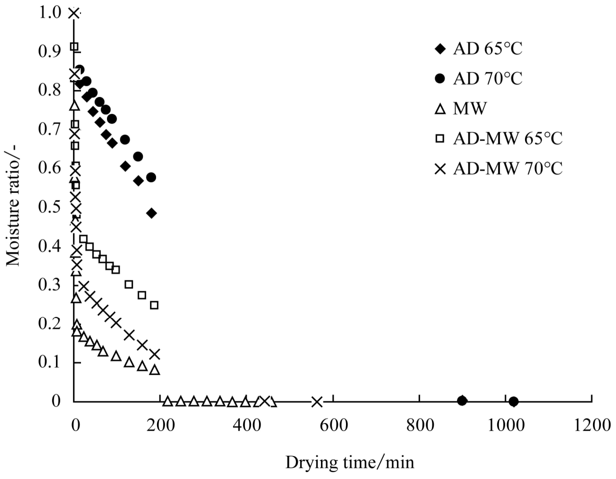

Figure 3 Curve of moisture ratio variation of potato slices vs. drying time at different drying methods

3.2 The effect of drying methods on physical properties

Figure 4 illustrates the effect of drying methods on porosity. The results of statistical analysis showed that drying method had a significant effect on porosity (p<0.05). The results denoted that combinative drying of microwave-hot air had the highest porosity at 70°C. Generally speaking, below equation is established as Fresh < MW < AD 65°C ≈ AD 70°C < MW-AD 65°C < MW-AD 70°C. The results showed that microwave drying can increase temperature in deep parts of the food due to dipolar electrical field and transfers water steam from deep parts to surface thus leading to porosity. On the other hand, in hot air drying, the hottest point of food is the surface of the sample and the coldest point is the depth of food that leads to lower porosity (Khraisheh et al., 2004).

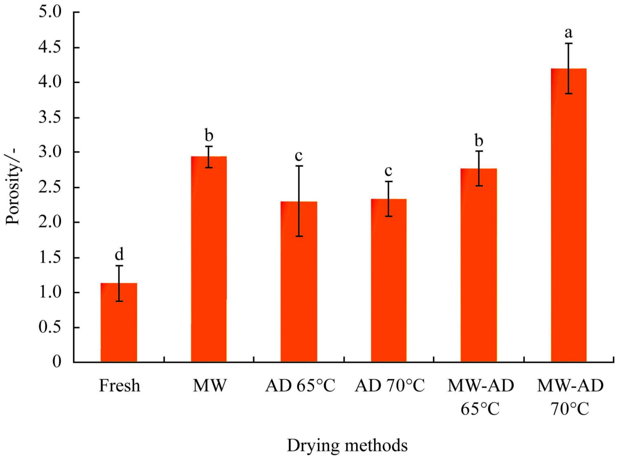

Figure 4 The effect of different drying methods on porosity during drying (The Same letters above the bars indicate no significant difference)

The results of variance analysis on the effect of drying method on potato rehydration are shown in Figure 5. The results showed that the type of drying method had a positive effect on rehydration at 95% probability level. The results denoted that dried sample with microwave method only has the highest rehydration and dried sample in combinative drying with microwave-hot air drying at 70°C has the lowest rehydration. There is not a significant difference between microwave-hot air drying at 65°C and hot air drying at 70°C. Drying rate and rehydration are as quality index of dried food. Rehydration value of drying in microwave is higher than dried samples with hot air drying. The hottest point is food surface and the coldest point is the depth of sample in hot air drying, in fact, food shrinks and plasmolyzes during drying and re-absorption of water gets complicated to some extent. Dipole filed produced in microwave drying leads to severe oscillation of polar molecules (especially water) and an increase in food temperature. Depth of food has higher temperature and water steam transfer from depth to food surface in this method. This state leads to porosity and swelling of the dry matter. Thus high porosity in microwave drying compared with hot air drying leads to higher rehydration (Khraisheh et al., 2004). Also heating reduces dehydration of starch and reduction in the elasticity of cellular wall and coagulates proteins, as a result reduces water absorption capacity of food. Foods dried in optimal conditions absorb water faster and more thoroughly. Overall, high temperatures drying produces more changes in texture compared with low and moderate temperatures drying (Heldman and Lund, 2007).

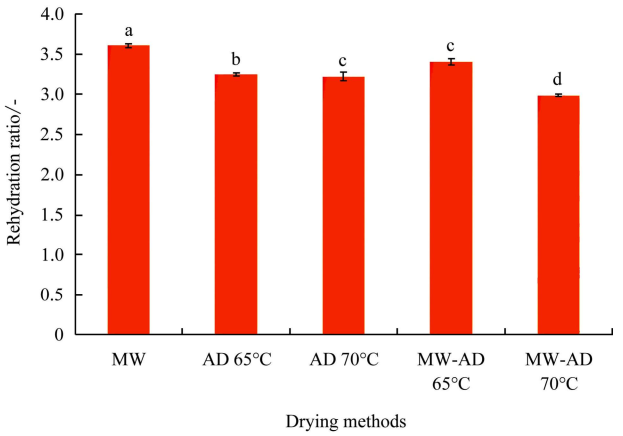

Figure 5 The effect of different drying methods on rehydration ratio during drying (Same letters above the bars indicate no significant difference)

The results for analysis of variance have been shown for the effect of the kind of drying method on potato shrinkage during drying in Figure 6. Type of drying had a significant effect on shrinkage at 95% probability level. The results denoted that the dried sample had the highest shrinkage in hot air method at 70°C and the lowest shrinkage in microwave method. There weren't any significant differences between 65°C and 70°C in combinative drying as in microwave-hot air drying.

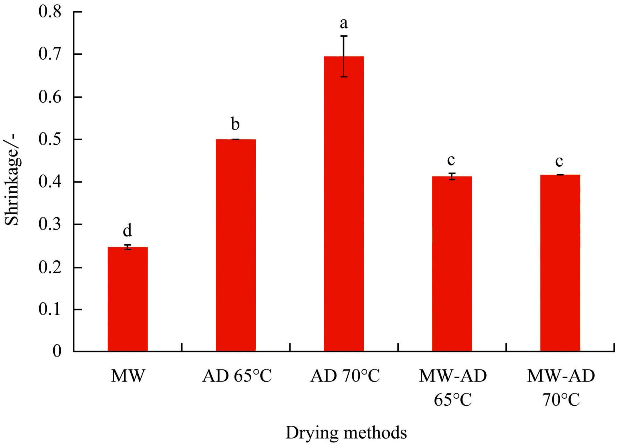

Figure 6 The effect of different drying methods on shrinkage during drying (Same letters above the bars indicate no significant difference)

Figure 7 shows the influents of drying methods on specific gravity changes. As clear, Figure 7 shows the type of drying method had a positive effect on specific gravity changes (p<0.05). The dried sample had the highest specific gravity in hot air drying at 70°C (SG = 0.985) and there weren't any significant differences with the dried sample by hot air drying at 65°C. There were no significant differences between 65°C and 70°C in combinative method microwave-hot air drying. Concerning the importance of this parameter it should be said that higher specific gravity of potato leads to decomposition of cubes during cooking. Dried cubes should be produced from low specific gravity potatoes for salads and soups in order to preserve their appearance in convenient foods (Lisinsca and Plisge, 1992).

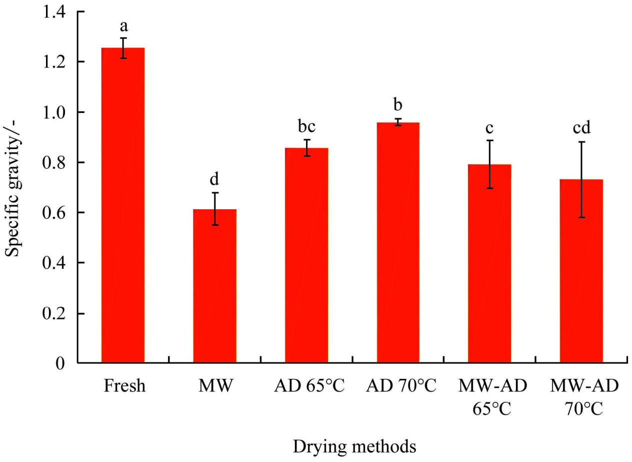

Figure 7 The effect of different drying methods on specific gravity during drying (Same letters above the bars indicate no significant difference)

3.3 The effect of drying methods on chemical properties

Table 5 shows the results of the color measurements of fresh and dried potato cubes. The results indicated that type of drying had a significant effect on lightness index (L) of dried samples (p<0.05). There weren't any significant differences between 65°C and 70°C in microwave-hot air combinative drying. Thus, the lowest and the highest amounts of L were for dried sample with hot air drying at 65°C and microwave-hot air combinative drying at 65°C, respectively. The type of drying had a significant effect on (a) and (b) values during drying (p<0.05). The highest and the lowest amount of a value was for dried sample with hot air drying at 70°C and only microwave dried sample, respectively. Analysis variants for b value showed that the lowest and the highest amount of b value were calculated for both dried samples with microwave-hot air combinative drying and hot air drying at 70°C. The kind of drying method had a significant effect on the general changes of potato cubes color (ΔE) ($p<0.05$). The lowest and the highest of ΔE in combinative method of hot air-microwave was at 65°C and the same was true for hot air drying. The results of analysis variance values of Hue and Chroma indicated that the type of drying method has a significant effect on parameters at probability level of 95%. As the highest and the lowest of Hue amount obtained in only microwave drying and convective hot air drying was at 65°C, respectively. Similarly, the highest and the lowest of Chroma amount was obtained in combinative drying as microwave-hot air drying and hot air drying at 70°C.

Table 5 The influence of different drying methods on color change

Drying methods	Color analysis factors					
	L	a	b	ΔE	Chroma	Hue
Fresh	62.76 ± 0.02^{a}	4.84 ± 0.02^{b}	32.44 ± 0.03^{bc}	43.39 ± 0.03^{e}	32.79 ± 0.03^{b}	81.51 ± 0.03^{b}
MW	54.92 ± 0.02^{c}	4.07 ± 0.04^{c}	32.51 ± 0.09^{ab}	49.01 ± 0.04^{b}	32.76 ± 0.08^{b}	82.85 ± 0.102^{a}
AD 65 °C	51.73 ± 0.01^{d}	5.93 ± 0.04^{a}	31.85 ± 0.62^{cd}	51.3 ± 0.35^{a}	32.39 ± 0.6^{bc}	79.44 ± 0.26^{d}
AD 70 °C	58.42 ± 1.09^{b}	5.98 ± 0.66^{a}	33.12 ± 0.1^{a}	47.07 ± 0.82^{c}	33.65 ± 0.01^{a}	79.76 ± 1.13^{cd}
MW-AD 65 °C	58.58 ± 0.63^{b}	5.27 ± 0.58^{b}	31.97 ± 0.55^{bcd}	46.08 ± 0.11^{d}	32.4 ± 0.56^{bc}	80.63 ± 1^{bc}
MW-AD 70 °C	57.96 ± 0.01^{b}	4.84 ± 0.03^{b}	31.45 ± 0.03^{d}	46.12 ± 0.005^{d}	31.82 ± 0.02^{c}	81.25 ± 0.06^{b}

Note: * Different letters in the same column indicate that the values are significantly different ($p<0.05$).

The results of analysis of variance for drying types on acid ascorbic content have been shown in Figure 8. The drying style had a significant effect on acid ascorbic content at 95% probability level. Dried samples with microwave method only have the highest acid ascorbic content and dried samples with hot air drying at 70°C contain the lowest acid ascorbic content. There isn't any significant difference at 95% probability level in combinative drying microwave-hot air drying between 65°C and 70°C. The results indicated that in most cases acid ascorbic content in microwave products is significantly higher than hot air drying products. This case is due to drying mechanism difference in the two methods. Decreasing heat transfer rate is due to low thermal conduction in hot air drying that leads to a damage in nutritional properties and oxidation of pigments and vitamins, one of the important factors is oxidation as the presence of oxygen and heat in acid ascorbic decomposition; loss of which is more significant than microwave dried products in hot air because drying time is considerably reduced by microwave rays. The results of Khraisheh et al. (2004) indicated that residue amount of ascorbic acid in microwave samples is higher than those of dried samples in hot air.

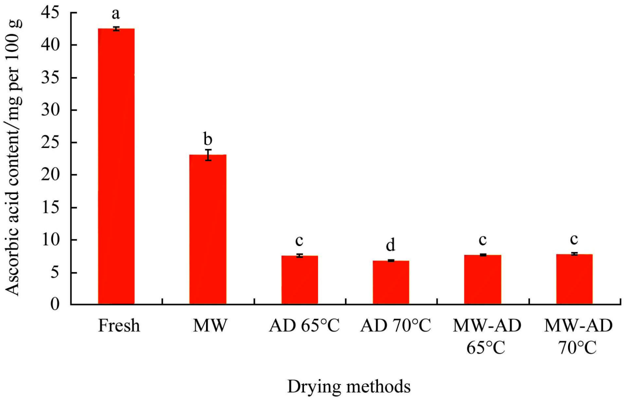

Figure 8 The effect of different drying methods on ascorbic acid content during drying (Same letters above the bars indicate no significant difference)

The results of analysis of variance for drying method typologies on starch content have been shown in Figure 9. The type of drying had a significant effect on the starch content ($p<0.05$). Microwave dried samples had the highest starch content and combinative method of microwave-hot air at 70°C had the lowest. Starch is among the ingredients that in case it is exposed to various processes, it gets apt for changes in both quantity and quality. The investigations on dried potato starch demonstrated that starch is broken down into amylases during drying by hot air because of an increase in water binding capacity, and a decrease of viscosity and high digestibility, then extracting starch from dried products in hot air is more facilitated than those dried in microwave (Kaaber et al., 2006). Similar results were reported for dried potatoes by Ramesh Yadav et al (Ramesh Yadav et al., 2005).

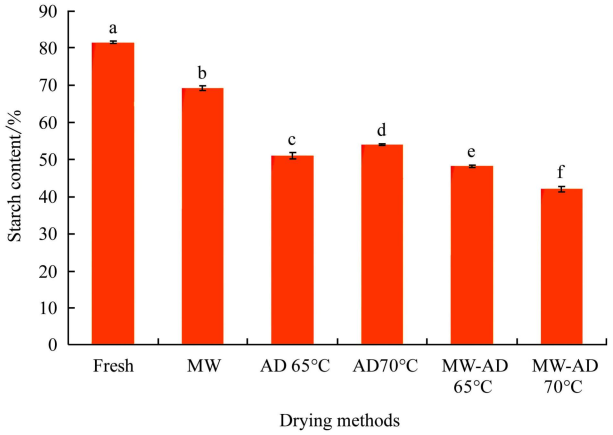

Figure 9 The effect of different drying methods on starch content during drying (Same letters above the bars indicate no significant difference)

The Analysis of variance results for the effects of drying method on gelatinization temperature have been shown in Figure 10. The drying method on gelatinization temperature at 95% probability level by Duncan's test is considerably significant. The dried samples with combinative method of microwave-hot air at 70°C have the highest gelatinization temperature and no significant difference is observed for those dried samples with hot air at 70°C. The dried sample has the lowest gelatinization temperature with hot air method at 65°C. Low power in a microwave leads amylase branches to be converted to reducing sugars; as a result, through loss of amylase, decrease of gelatinization temperature is ineluctable.

3.4 Predicting moisture ratio by Artificial Neural Approach

In this research, a combination of different layers and neurons with different activation functions were used for modeling perceptron neural networks. Neural network with one and two hidden layers, 1-16 neurons were selected randomly and network power was estimated to predict potato moisture ratio. To obtain suitable training, epoch experimental network was used with variable numbers of neurons (1-16 neurons) and suitable training epoch number was determined for each activated function. In order to identify the best training epoch, trial and error method was used (Applied training epoch numbers were as follows: 100, 1,000, 1,500, 2,500, 5,000 and 7,000). The best training epoch for *logsig* and *tanh* activation function obtained 5,000 and 5,000, respectively. The results of MLP were optimized with *logsig* and *tanh* activation function and topologies in different cases achieved as indicated by Figure 7. It shows variation of MRE values neuron numbers to predict moisture ratio. Investigating the obtained results for MLP with *logsig* activated function with one and two hidden layer has been shown; topologies 3-10-1 (i.e. network with 3 inputs, 10 neurons in the first hidden layer and one output) and 3-16-16-1 (i.e. network with 3 inputs, 16 neurons in the

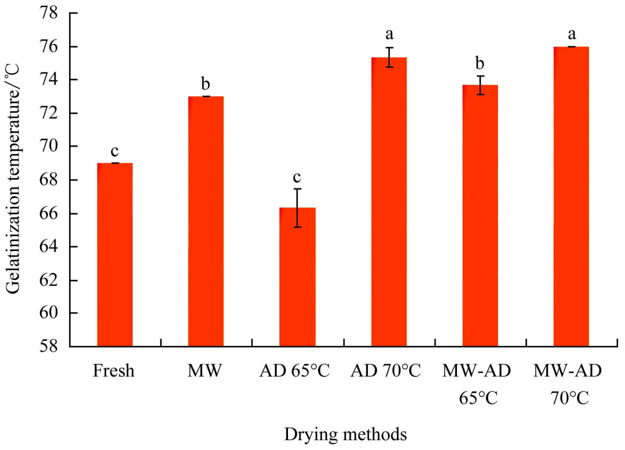

Figure 10 The effect of different drying methods on gelatinization temperature during drying (Same letters above the bars indicate no significant difference)

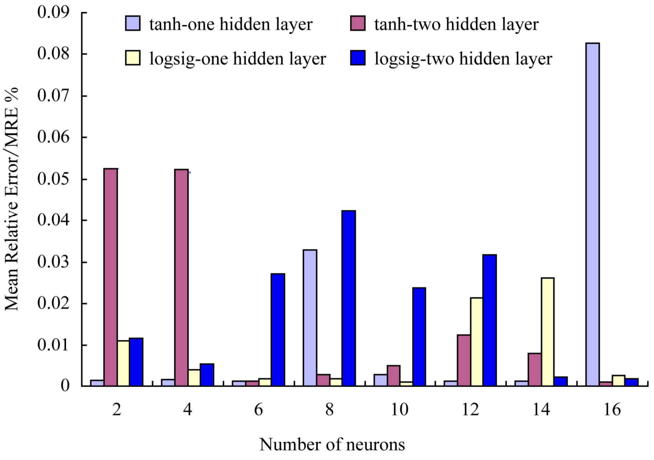

Figure 11 The variation of relative error values vs. neuron number to predict moisture ratio with different activation functions during drying with different methods

first and second hidden layer and one output) had the best capacity to predict moisture ratio, respectively. In this case, R^2 values were calculated as 0.997 and 0.995, respectively. The results of MLP with *tanh* activation function showed that neural network with topologies 3-16-16-1 had the best capability to optimize moisture ratio; accordingly, this network could predict the moisture ratio with R^2 = 0.994 (MRE value in this case was calculated 0.001055%) (See Figure 11).

The results of compressing artificial neural network of different functions indicated that *logsig* function with 10 neurons in hidden layers were selected as the best configuration to predict moisture ratio of dried potatoes. Model Sensitivity diagram of predicted values by MLP network with *logsig* activation function against experimental values for the best configuration (i.e. structure of 3-10-1) indicated that data were randomly located around the regression line. This could be a reason for carefully evaluating the neural networks to predict the moisture ratio of potato during drying (Figure 9). (See Figure 12).

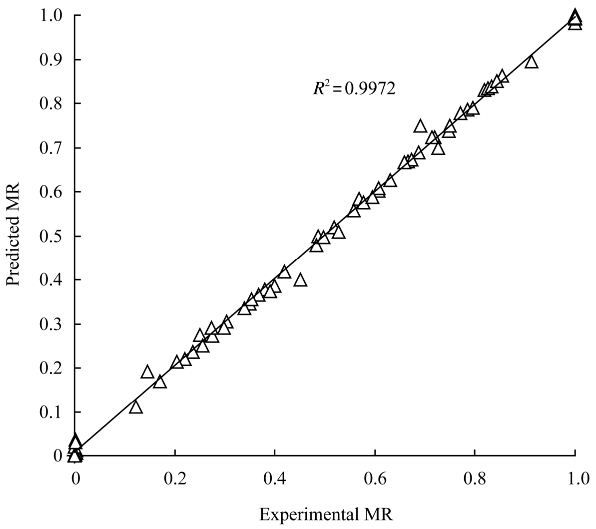

Figure 12 Comparison of experimental and predicted MR values obtained by goodness activation function of ANN (*logsig*)

4 Conclusions

In this study, we investigated the effect of different drying methods on the physical properties and qualitative characteristics of potatoes. Different drying methods including microwave drying (constant microwave power equal 900 W), air drying and combined microwave and air drying were used to dry potato cubes. The qualitative and physical parameters of dried samples including specific gravity, porosity, rehydration, shrinkage, vitamin C, color, starch, gelatinization temperature, drying rate and time were determined. According to the obtained results, we concluded that the microwave drying was better for drying potato cubes. Also, in this research, ANN trained by back propagation algorithms was developed to possibly predict moisture ratio based on three input variables. Different factors including learning epochs (100 to 7,000), number of neurons (2 to 16) and type of activation function in hidden and output layers (*logsig* and *tanh*) were used in order to find the best configuration of ANN to monitor the moisture ratio during drying. The results indicated that, ANN with *logsig* activation function based on 10 neurons in first hidden layer (i.e. 3-10-1 topology) was able to estimate moisture ratio with higher R^2 value (0.9972), whereas Logarithmic and Page models (as the best model) could predict moisture ratio with maximum R^2 value equal 0.996. Taken as a whole, the comparison of obtained results of ANN and empirical modeling showed that ANN (as a novel and non-destructive method) had a higher capability compared with classical modeling to predict moisture ratio.

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