Available online at www.elixirpublishers.com (Elixir International Journal)

Food Science

Elixir Food Sci. 77 (2014) 29220-29225

ISSN: 2229-712X

Comparison between Artificial Neural Networks and Khazaei Mathematical model for Moisture Content Prediction in Three Varieties of Bean

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ARTICLE INFO

Article history:
Received: 27 July 2014;
Received in revised form:
5 December 2014;
Accepted: 16 December 2014;

Keywords
ANNs, MLP, RBF,
Soaking,
Water uptake.

ABSTRACT

In this research modeling of moisture content of three different varieties of bean (Talash, Sadri and MahaliKhomein) was studied during soaking by applying Khazaei mathematical model and artificial neural networks (ANNs). The procedures were carried out in three experimental temperatures (5, 25 and 45˚C) in distilled water. Water abortion characteristics of samples were considered by measuring the increase in the mass of seeds with respect to time. Amulti layer perceptron (MPL) and radial basis function (RBF) approach were used with three layers of neurons, in designing ANNs. The soaking temperature and time were used as input parameters and the moisture content was used as output parameter of ANNs. To evaluate the prediction of mathematical and ANNs model, coefficient of determination (R^2),root mean square error (RMSE) and distribution of residual errors plot were used. The results indicated that the MLP approach using back propagation training structure, Broyden- Fletcher-Goldfarb- Shanno(BFGS) algorithm and 2-6-1 topology of the network achieves the best results for moisture content estimating in three studied varieties of bean. Besides that, the instant moisture content curves based on temperature and time independent variables using MLP method expressed with increasing the time and temperature of seed immersion, water absorption is increasing.

Introduction

In comparison animal protein,the plant protein is more easily and economical way to obtain. This reason lead to plant protein has a special place in human nutrition in all over the word. After the grains,the cereals are the second most important human food resources (MajnoonHosseini, 1996). Beans are one of the most important member of legume family that they have an important role as a human food, protein and calorie resource (Graham and Ranalli, 1997). The bean seeds have 20-25% amount of protein and 50-56%amount of hydro carbons and in comparison to cereals have twice amount of protein. For the reasons were mentioned before the cultivating area of this product is increasing in all over the world (Hungria*et al*., 2000).

In Iran, the planting area of common beansare about 50% of whole beans planting area. The modified varieties of common beans are: “Talash”, “Daneshjoo”, “MahaliKhomein” and “Omid” with approximately 2.5 tons product in each hectare and this amount can increase to five tons per hectare using appropriate cultivate methods (MajnoonHosseini, 1996). “Sadri” variety was obtained from CIAT institute. The average amount of production per hectare for this variety is 2464 Kg and in comparison with “MahaliKhomein” variety (2240 Kg per hectare) has a better performance. Now a days, “Sadri” variety is the best big common bean for marketing.

Soaking the bean seeds during the peeling and cooking is a common approach to soften the shield and core. The amount of water absorption by seed during soaking is different. The size of the seeds, water temperature and the immersion time are the effective parameters to the water uptake of seeds. It was observed by many researches that the higher temperature, lead to reduce time need of mailing the seeds to saturated moisture content (Montanuci*et al*., 2013; Shittu*et al*., 2012; Bello *et al*., 2010; Oliveira *et al*., 2013; Abu-Ghannam and McKenna, 1997; Kashaninejad*et al*., 2007).

The most common mathematical models that have been used for modeling moisture content of crops in soaking and drying can be named Page, Weibull, Binomial and Peleg model (Shafaei and Masoumi, 2014a). Investigation into models was proofed that all recommended models by researchers have an adequate describe the hydration and dehydration kinetics of agriculture products (Shafaei and Masoumi, 2013c; Aghajani*et al*., 2010). Some researchers modeled water absorption of chickpea seeds using 14 standard model. They found out the Binomial model was the most suitable model in order to predict moisture content of different types of chickpea during soaking (Shafaei and Masoumi, 2014b).

Previous studies showed that kinetics of water absorption of agricultural products includes an initial and second phase that have faster and lower water absorption rate, respectively. (Espert *et al*., 2004; Machado *et al*., 1998; Machado *et al*., 1999; Sayar *et al*., 2001). The second phase usually named relaxation phase, complete to the saturated moisture content of seed. The major problem of all experimental mathematical models of water absorption is that they do not present sufficient assessment for the second phase. Based on this, researchers used the equation (1) to describe hydration and dehydration kinetics of agriculture products (Khazaei, 2008a; Khazaei2008b; Khazaei and Daneshmandi, 2007).

$$M_t = M_o + M_{ret}(1 - \exp(-t/T_{ret})) + K_{rel}t \quad (1)$$

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Where $M_t$is moisture content at time t (d. b. %), $M_o$is initial moisture content (d. b. %), $M_{ret}$is retardation moisture content in the first phase of soaking (d. b. %),T_{ret}(time of retardation) is the required time to approach approximately 63% of the retarded moisture content (hr) and $K_{rel}$is the rate of water absorption in the relaxation phase (hr^{-1}%). The lowest amount of T_{ret}shows the highest rate of water absorption in the first phase of soaking. Also, K_{rel}shows the rate of water absorption in the relaxation phase and it is calculated by determining the slope of the tangent line on the last part of water absorption curve (Figure 1).

The advantage of the model respect against other empirical and semiempirical models is ability of the model to determine all the constant parameters directlyfrom the water absorption curve. The model is also able to describe the second phase ofwater absorption (the relaxation phase) (Khazaei and Mohammadi, 2009). Generic models provided by the researchers were able to analyze the behavior of moisture content of seeds in the first phase during soaking, while for seed with long water absorption part in second phase, it is important to determine relaxation phase. Therefore, applying Khazaei model provides this possibility.

Some previous investigator used the Khazaei model to describe water uptake characteristics of three varieties of chickpea seeds. They found that the model has an acceptance precision to predict moisture content of seeds during soaking (Shafaei and Masoumi, 2013a). Also, other searches demonstrated this fact about barley soaking in three experimental temperatures (Shafaei*et al*., 2014c). The disadvantages of the mathematical models which is used by researchers is one variable (time depended) and changing the coefficients of models affected by temperature.

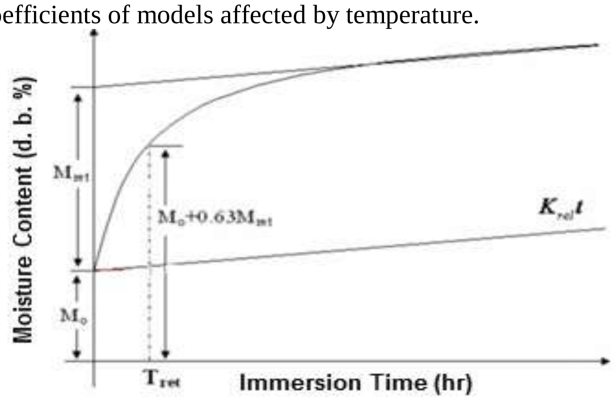

Figure 1. A depicted model for modeling water absorption curves (Mohsenin, 1986)

The intelligent prediction methods use the hidden information of the obtained data to extract the best correlation between them and use this function for other situations. The ANNs is one the most important approach for the artificial intelligence that saves the information of data as the weight of network during the training process by inspiration of human brain (Dayhoff, 1990). ANNs approach is used successfully in prediction of many natural processes. This approach has many advantages to statistical and mathematical modeling ways. In comparison with linear regression, ANNs do not force the predicted data to perch in mean value boundaries, therefore keeps the real dispersal of data. It provides the possibility of increasing and decreasing the number of input and output layers using trained ANNs to predict. Thus, it can be generated the model with multi variables and targets (Heristev, 1998).

Some researchers used MLP and RBF approach of ANN to model the chickpea seeds moisture content during soaking procedure. They found that MLP method has sufficient accuracy for prediction the amount of absorbed water inchickpea soaking (Shafaei and Masoumi, 2013d).

The scoop of current study is prediction of instant moisture content for three varieties of bean (“Talash”, “Sadri” and “MahaliKhomein”) during soaking process in three excremental temperatures (5, 25 and 45˚C) using MLP and RBF method of ANN and compare the results of themto Khazaei mathematical model of water absorption of agricultural products.

Material and methods

Preparation of the samples

“Talash”, “Sadir” and “MahaliKhomein” variety of bean were gathered from the bean collection center inKhomeinCity, Iran. Before the tests, the injured seeds and external materials were abolished from the samples. Then the collected seed were categorized in three different classes according to their size. The medium sized seeds were used for examinationin other to eliminate the effect of seeds size on water absorption. The initial moisture content of three studiedverities of seeds were determined based on ASAE S352.2 DEC97 standard (ASAE, 1999). Three varieties of bean had initial moisture content fewer than 10% (d. b. %) and they were notsignificantly different at $P>0.05$.The distilled water and containers were located in the same temperature as the temperature used for the test some hours before the soaking trail.

Experimental apparatus

The test was performed in three different temperatures (5, 25 and 45˚C) in Refrigerator, Opened space and oven for each variety, respectively. The possibility to gelatinize the seeds can take placewhen the temperature goes higher. In each test 10 medium sized seed were picked randomly and weighted with an electronic balance (AND brand, GF-400 model and made in japan) via accuracy of 0.001 grams. Then the seeds were located in foam flasks that contained 200 mg of distilled water (Kashaninejad and Kashiri, 2008).After specific time (5, 10, 15, 30, 60, 120 minutes and etc.) the seeds were took out and weighted after drying the facial moisture with a tissue. The digital stopwatch and balance were used to measure time and weight before and after every soaking trail, respectively. In other to reduce error, each test was completed three times. The absorbed water was determined using Equation (2) (McWatters*et al*., 2002):

$$W_a = \frac{W_f - W_i}{W_i} \times 100 \quad (2)$$

Where W_a is the absorbed water (d. b. %) and W_f and W_i are weight of the seeds after and before the soaking process, respectively (g).A time table was designed to execute tests in specific time levels. The trails were completed when the seed moisture content reached to the saturated moisture content. According to Vishwakarm*et al*. (2013), the trail when completed that losses of soluble solids mail to 1% of the initial samples mass. Thus, at each stage, the amount of solid material dissolved in water was controlled by measuring density of distilled water and drained water in each experiment.

Development of ANNs model

The MPL and RBF approach via three layers of neurons were used, in order to design ANNs. The first layer was the input layer for temperature and time (independent variables), the second layer was the hidden ones and the third one was the output layer for the moisture content as the dependent variable. 70% of obtained data from soaking trails was used for training, 15% for evaluating and 15% for testing the designed ANNs model. The composite parameters such as type of learning algorithm, number of the hidden layers, neurons, learning cycles and learning coefficient were defined during ANNs learning by trying and testing method in order to increase the model's precision and prevent data over fitting (Fletcher, 1987).

Due to the large number of algorithms and training functions for training ANNs, in each method, to train, evaluation and examination ANNs, non-linear algorithms that reduce the slope, coupled slope, BFGS, RBF technic and trigonometric, logarithmic, linear, logical Gaussian functions were used . Schema architecture of ANNs can be seen in Figure (2).

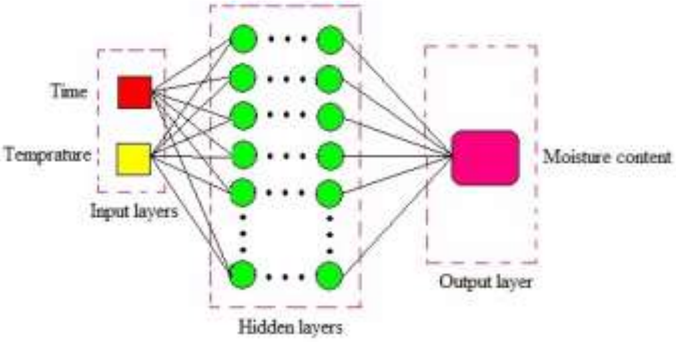

Figure 2. Schema of designed ANN

Evaluation of Khazaei model and ANNs

Khazaei model were fitted to the data and model coefficients were calculated for three varieties of beans in the three experimental temperatures.To evaluate the model, two parameters, R^2 and RMSEwere determined based on equations (3) and (4), respectively (Garcia-Pascualet al., 2006; Giner and Mascheroni, 2002; Shafaei and Masoumi, 2013b).Besides these parameters, distribution of residual errors plot of three studied varieties of bean were studied.

In order to select the best network structure, according to the highest predicting of seeds moisture content, R^2, RMSEand distribution of residual errors plot of moisture contentinthe evaluation stage of ANNs development were used based on equation (3) and (4), respectively.The best appropriatenetwork structuresalongalgorithmsand functions used ofMLP andRBF were selected based on maximum value of $R^2$and minimum value of RMSE and distribution of residualof moisturecontent (Kashaninejad*et al*., 2009).

$$R^2 = \frac{\sum_{i=1}^{N}(M_{exp,i}-M_{exp\ ave})^2-\sum_{i=1}^{N}(M_{exp,i}-M_{pre,i})^2}{\sum_{i=1}^{N}(M_{exp,i}-M_{exp\ ave})^2} \quad (3)$$

$$RMSE = \left[\frac{1}{N}\sum_{I=1}^{N}(M_{pre,i}-M_{exp,i})^2\right]^{1/2} \quad (4)$$

Where, *Mexpave*is average moisture content observed (d. b. %), *N* is the number of data, *Mpre,i*the i[th] predicted moisture content (d. b. %) and *Mexp,i*is the i[th] experimentally observed moisture content (d. b. %).

Results and discussion

Assessment of Khazaei model

Constants of model were obtained at three different temperatures, R^2andRMSEare shown in Table (1). Fitted model on water absorption data of three studied varieties of bean areobserved in figure (3). Distribution of residual errors plot of moisture contentof bean are shown in figure (4). These charts were used to show the data distribution and predicted error. Comparison of R^2 and RMSE of fitted model was indicated that, the model has sufficient precision to predict moisture content of bean during soaking. Although, the model has sufficient precision, but it has not enough accuracy to predict the moisture content of bean seeds. The maximum value of $R^2$was 0.942 and minimum value of RMSE was 2.797, which demonstrate the suitability of the model for modeling the experimental water absorption characteristics of bean samples.Despite the khazaei model was suitable model for predicting water uptake of bean, but, in some cases the residual error of modeling was high. In case of "Talash" variety, maximum residual error of modeling was 12.717 in 45°C. Results show a maximum value of residual error, 9.196 and 10.826, 5°Cand 45°C, for "Sadri" and "MahaliKhomein" variety, respectively. Some researchers reported similar results in barley soaking (Shafaei*et al.,* 2014c). Other studies were demonstrated that Khazaei model has acceptable ability to predict water absorption values of chickpea seeds (Shafaei and Masoumi, 2014d).

The model has been applied in drying procedure by researchers. They found that the model had an acceptable precision in predicting drying kinetics of sesame seed (Khazaei and Daneshmandi, 2007).

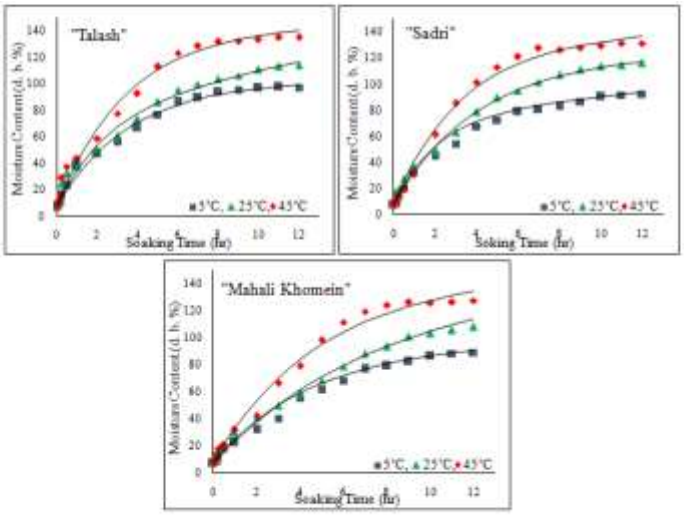

Figure 3. Fitted Khazaei model on water absorption data of bean

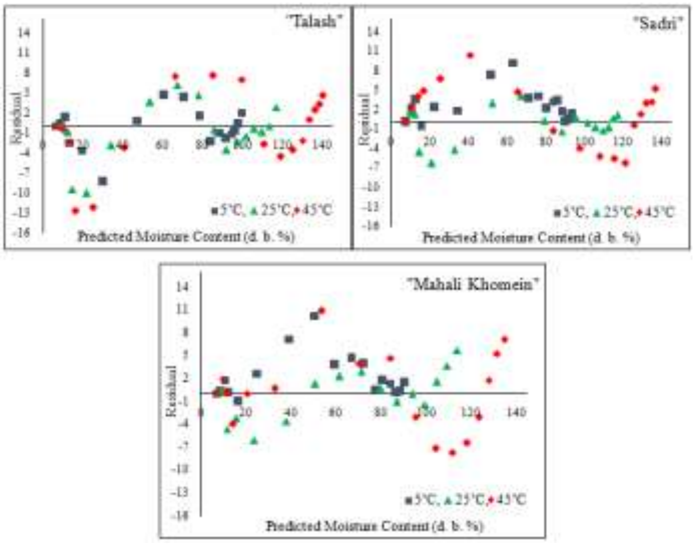

Figure 4. Distribution of residual errors for Khazaei model for soaking seeds

Opting the best ANN structure

Predicted values against measured values of moisture content which is depict predicting precision and residual error plots of moisture content that show data distribution and test error were shown in figures (5), (6) and (7) for MLP and RBF methods, respectively. Results of comparison of two ANN methods indicated that although, RBF method has good accuracy to predict moisture content of seeds (figure 8), but it has not an acceptance precision to estimate seeds moisture content rather than MLP method. The maximum error of predicting water absorption of "Talash" variety were 4.169 and

10.061 for MLP and RBF method, respectively. Similar results were depicted in figure (9) for two other varieties. Table (2) reports the most appropriate eminent network structure of MLP and RBF method to predict moisture content associated with R^2 and RMSEin the evaluation stage. MLP approach achieved the best prediction for three studied varieties of bean duo to error back propagation structure, BFGS algorithm, 2-6-1 topology, Fewer neurons in the hidden layer, upper and fewer R^2 and RMSE respectively, by comparing of figures (5) and (6) and table (2).

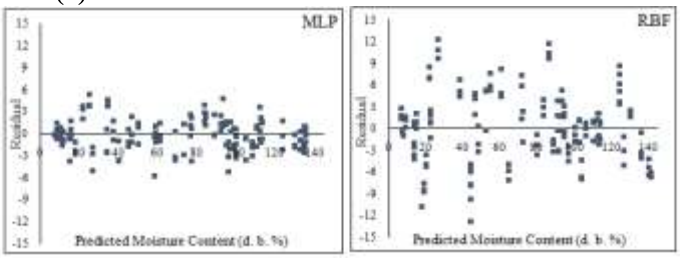

Figure 5. Residual distribution of ANN errors for "Talash" variety

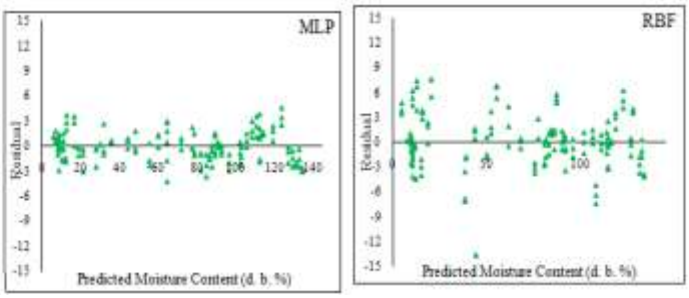

Figure 6. Residual distribution of ANN errors for "Sadri" variety

Back propagation algorithm is used to train ANN based on MLP method. In the first, network calculation is done from input forward to output. Then, the calculated error values are released to the prior layer, using error back propagation algorithm during training step. At the beginning, the output layer is calculated layer by layer and the output of each layer is the input of the next layer. In back propagation, initially output layer is adjusted because, desirable value exist for each neuron of output layer; Weights to bead justed using them and timeliness rules (Khanna, 1990).

RBFmethodhas a very strong mathematical basisdeep root in arrangement theory for estimating problems. The training of the network parameters (weight) between the hidden and output layers happen in a supervised mode based on target outputs (Kashaninejad*et al*., 2009). Therefore, the MLP method has excellence than RBF method in modeling. As follow as, MLP modeling was acceptance prediction for water absorption of three studied varieties of bean during soaking, in this paper. Similar to our finding, superiority of MLP approach rather than RBF method in agriculture products soaking and drying have been reported by researchers, respectively (Kashaninejad*et al.*, 2009; Aghajani*et al.*, 2012).

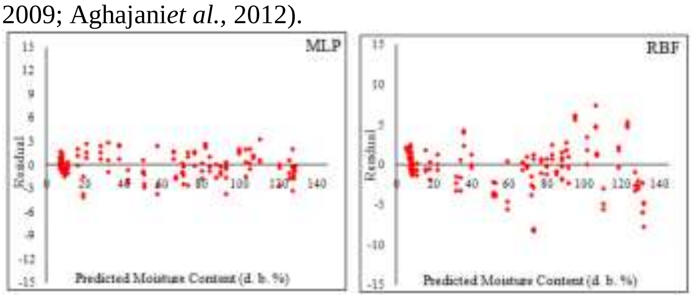

Figure 7. Residual distribution of ANN errors for "MahaliKhomein" variety

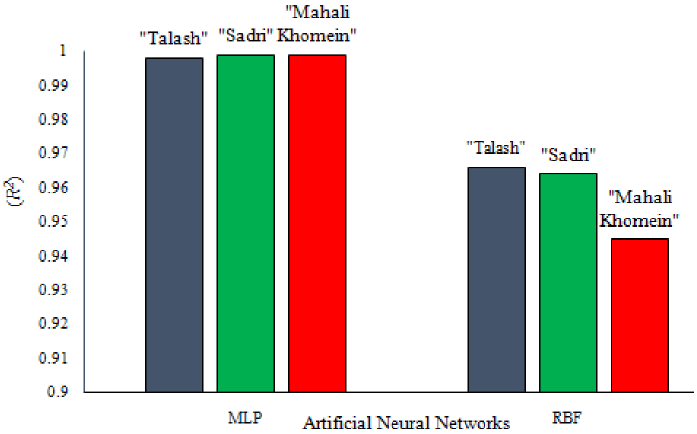

Figure 8. Comparison between precision of MLP and RBF method of ANN for predicting moisture content of three varieties of bean

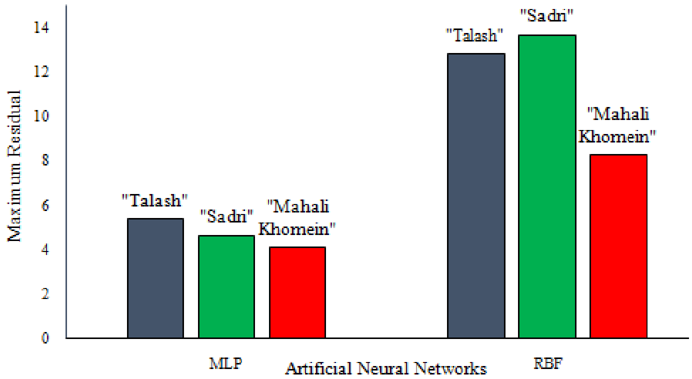

Figure 8. Comparison between maximum residual of MLP and RBF method of ANN for predicting moisture content of three varieties of bean

Comparison between Khazaei and ANNs model

Moisture content predicted by the Khazaei and ANNsmodel are compared to the observed moisture contentaccording to the table (1) and (2). These results demonstrate that the concurrence is very good in ANNs and theypredicted the observed moisture contents well throughoutthe various varieties.These models were compared based on the R^2, RMSE and the results about average residual errors of estimatingmoisture content of seeds. Therefore, the suitable model to describe soaking characteristics of three studied varieties of bean was found to be the MLP methodwith the highestR^2 = 0.999, minimum RMSE = 0.01005and average residual error = 0.0604. In accordanceof result, similar results have been reported for good ability of MLP method versus mathematical model to predict moisture content of barely, chickpea, wheat kernel and sorghum, respectively (Shafaei*et al*., 2014c; Shafaei and Masoumi, 2013d; Kashaninejad*et al*., 2009; Kashiri*et al*., 2012).

Predicting of moisture content curves

In figure (9), water uptake curves of three studied varieties of bean ("Talash", "Sadri" and "MahaliKhomein") were shown based on the best structure of MLP method of ANN. The results demonstrated that with increasing of immersion temperature, water absorption of seeds increased in specific time, significantly ($p<0.05$). On the other hand, by fixing the temperature of seeds during soaking, time increment of seeds immersion trend to intensify water absorption, significantly ($p<0.05$). Applying of higher temperatures on short time has resulted to achieve upper moisture content in shorter time during soaking, by comparing rate of water uptake of seeds versus time and temperature of immersion.

Table 1. The coefficients and statics parameters of Khazaei fitted model of soaked bean

Type	Temperature (°C)	M_{ret}(d. b. %)	T_{ret}(hr)	K_{rel}(hr^{-1}%)	R^2	RMSE
Talash						
	5	91.52	3.511	0.286	0.925	4.284
	25	71.90	2.464	3.160	0.936	5.564
	45	135.5	3.529	0.136	0.902	6.109
Sadri						
	5	67.96	2.125	1.540	0.942	3.756
	25	108.1	3.880	0.523	0.934	2.871
	45	119.9	3.155	1.003	0.915	5.048
MahaliKhomein	5	80.04	4.621	0.627	0.926	3.981
	25	112.0	6.804	1.128	0.939	2.797
	45	122.3	4.470	1.117	0.914	5.346

Table 2. The best structure of two methods of MLP and RBF to predict moisture content of three varieties of bean during soaking

Type	ANN method	Number of neurons in hiddenlayers	(R^2)	(RMSE)	Training algorithm	Operation function in hidden layers	Operation function in output layer
Talash	MLP	6	0.998	0.13624	BFGS	Trigonometric	Logical
	RBF	26	0.966	0.73413	RBFT	Gaussian	Linear
Sadri	MLP	6	0.999	0.06865	BFGS	Logarithmic	Logarithmic
	RBF	26	0.964	0.40705	RBFT	Gaussian	Linear
MahaliKhomein	MLP	6	0.999	0.04005	BFGS	Logical	Logarithmic
	RBF	26	0.945	0.12200	RBFT	Gaussian	Linear

Similar results have been reported for various legumes such as soybean, chickpea, cow chickpea, and chick peanuts (Turhan*et al*., 2002; Sopade and Obekpa, 1990; Sopade and Kaimur, 1999; Pan and Tangratanavalee, 2003).

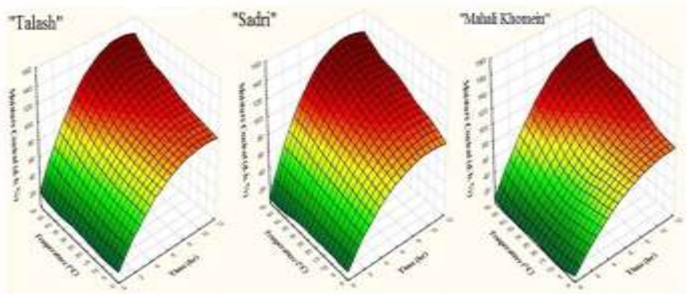

Figure 9. Predicted water absorption surface of ANN based on MLP method against temperature and time for seeds

Conclusions

Water absorption modeling results of three studied varieties of bean indicated that, despite of good accuracy of Khazaei model to predict moisture content of seeds, the model had not acceptance precision against ANN methods. In case of ANN methods, MLP method had higher precision rather than RBF method to predict moisture content of three studied varieties of bean (“Talash”, “Sadri” and “MahaliKhomein”) during soaking. Based on Prediction MLP method of ANN, increasing of immersion time had affected on water absorption of seeds, significantly. By time raising of soaking in constant water temperature, moisture content of seeds increased. Besides that, seeds water absorption increased with increasing water temperature from 5˚C to 45˚C, in the same time. In the bean soaking, use of higher temperatures on short time has affected to reach saturate moisture content in shorter time.

Acknowledgment

The authors would like to acknowledge Ms. Roshan’s cooperation in carrying out the tests of study from department of agricultural machinery, faculty of agriculture, Isfahan university of technology.

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