Journal of Food Science and Technology (Iran)

Homepage:www.fsct.modares.ir

Scientific Research

Application of microwave pretreatment to increase mass transfer rate during carrot slices drying process

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ABSTRACT

The drying process is one of the methods of processing vegetables and fruits, helping to reduce the volume of the product, facilitate transportation, increase preservation ability, and reduce microbial activities. As a fast and effective heat source with thermal and non-thermal effects, microwaves can directly affect food and thus accelerate physicochemical reactions and drying rates, and produce high quality dried products. The purpose of this research is to use microwave pretreatment to increase the mass transfer rate in the drying process of carrot slices and to model the process using the genetic algorithm-artificial neural network method. In this study, the effects of microwave treatment time at five levels of 0, 15, 30, 45, and 60 seconds on the drying time and moisture content of carrot slices were investigated in three replications. This process was modeled using the genetic algorithm-artificial neural network method with 2 inputs (microwave processing time and drying process duration) and 1 output (moisture percentage). The results showed that by increasing the microwave treatment time, the rate of moisture removal from the samples increased and thus the drying time decreased. Different training algorithms were evaluated and the Levenberg–Marquardt algorithm was chosen as the best algorithm. Based on modeling data analysis, the Perceptron artificial neural network with 2-5-1 structure is the most suitable network to predict the moisture content of microwaves-treated carrot slices. In this study, the values of mean squared error (MSE), normalized mean squared error (NMSE), mean absolute error (MAE), and correlation coefficient (r) for predicting the moisture content of carrot slices during drying process were equal to 5.298, 0.006, 1.650, and 0.997, respectively. The results of the optimal neural network sensitivity analysis showed that the drying process duration was the most effective factor in predicting the moisture content of carrot slices.

ARTICLE INFO

Article History:

Received:2023/9/8
Accepted: 2023/10/9

Keywords:

Genetic algorithm-artificial neural network,
Levenberg–Marquardt,
Microwave,
Perceptron,
Sensitivity analysis.

DOI :10.22034/FSCT.20.145.139

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1- Introduction

Growing concerns about product quality and production costs encourage researchers to further study and research alternative hybrid drying technologies [1]. In the microwave dryer, the water in the food absorbs the microwave energy and turns it into heat. The heat generated in the food material is mainly due to dipole and ionic mechanisms. These are usually directed by the oscillating electric field produced by the microwaves and ultimately lead to an increase in the temperature of the product [2]. Using microwaves as a pretreatment or combination is an efficient drying method. This method can be used to speed up the drying of special foods, especially fruits and vegetables. Advantages of combined microwave drying include shorter drying time, better quality of the final product, and flexibility in producing a wide variety of dried products; However, the current applications of microwaves are limited to scientific research, small industries and a small portion of fruits and vegetables due to high start-up costs and relatively complex technology compared to conventional convective drying [3-5]. The microwave method was used for treating and drying various agricultural products, including pomegranate arils [6], apple [5, 7], garlic [8], carrot [9], myrtus fruit (*Myrtus communis* L.) [10], cherries [11], green olives [12] and sprouted lentils [13], and from the results of these studies, it can be concluded that the effective moisture diffusivity coefficient was increased, the drying time was decreased, energy consumption was reduced, quality characteristics was improved, and phenolic and flavonoid compounds were preserved. A group of researchers reported that the use of microwave pretreatment preserves the color and antioxidant activity of the final product [14].

In the artificial neural network method, the network consists of several layers including input layer, hidden layer and output layer. Each layer consists of several neurons, among which the number of neurons in the hidden layer is of particular importance to receive the answer. Neurons are the smallest models of the neural network. In this method, the network is trained through experimental data and weights are determined to determine the relationship between layers. The error between the actual and predicted response variable is fed back to the input network to achieve the appropriate response [15-17].

The topology of any network shows the relative position of cells in the network (number, grouping and connections). Topology is actually the hardware

[DOI: 10.22034/FSCT.20.145.139]

connection system of neurons, which together with the relevant software (mathematical method of information flow and calculation of weights) determines the type of neural network operation [18]. This network can analyze experimental data and effectively communicate nonlinear relationships and finally model and draw conclusions [19, 20].

Genetic algorithm is an optimization method that involves repeating the search to determine the input values in order to obtain the desired output. This algorithm mimics biological evolutionary systems such as selection, crossover, and mutation [16, 20]. The genetic algorithm method is a parallel search algorithm based on natural selection and Darwin's theory of evolution. In this method, an attempt is made to mathematically model the natural selection system. In this method, only the values of the objective function, which must be clearly defined at the beginning and a combination of all the desired objectives, are used to guide the search, and there is no need to know how the variables change [18]. Currently, the combination of genetic algorithm with artificial neural network is widely used to model processes and predict system responses [16, 21].

Microwave pretreatment can greatly accelerate the drying speed and shorten the drying time of the product. In this research, the use of microwave pretreatment at five times of 0, 15, 30, 45, and 60 sec to increase the mass transfer rate during the drying process of carrot slices was investigated and the process was modeled by genetic algorithm-artificial neural network method.

2- Materials and methods

2-1- Preparation of raw materials

To perform the experiments, carrots with same size were procured from Hamedan city. To determine the moisture content of the samples, carrot slices were placed in a laboratory oven (Shimaz, Iran) with a temperature of 105°C for 5 hours. The initial moisture content of carrots was 90.77% on wet basis.

2-2- Microwave treatment

To apply microwave treatment, carrots were first cut into slices with a thickness of 0.5 cm by an industrial slicer (Girmi, model AF-23, Italy). Then the carrot slices were treated for 0 (control sample), 15, 30, 45 and 60 sec by a household microwave device (Delmonti, model DL740, Italy).

2-3- Drying process

The treated carrot slices with microwaves were placed in a thin layer inside a forced oven (Shimaz, Iran) with a temperature of 70°C. The weight changes of the samples during drying until reaching a constant weight were recorded by a digital scale (Lutron, Taiwan) with an accuracy of ± 0.01 g.

2-4- Genetic algorithm-artificial neural network modeling

Modeling of the drying process of microwave-treated carrot slices to predict the percentage of moisture (based on wet weight) was done by genetic algorithm-artificial neural network method, by three-layer perceptron feed-forward neural networks. The topology of multilayer perceptron networks is completed by the error backpropagation learning [18]. In this study, two inputs (microwave treatment time and drying process duration) and one output (moisture percentage) were considered. Neurosolution software (version 5, NeuroDimension, Inc., USA) was used for modeling. In this software, by changing the type of activation function (Linear, Sigmoid and Hyperbolic tangent); the number neurons in hidden layer (1-20), the number of data used for training, validating, and testing, and learning algorithms, the best network structure to achieve the optimal network were investigated. In order to evaluate the created neural network, the indexes of mean square error (MSE), normalized mean square error (NMSE), mean absolute error (MAE), minimum absolute error, maximum absolute error and correlation coefficient (r) were used [17].

3. Results and Discussion

3-1- Effect of microwave pretreatment

Microwave method is an interesting method for pretreatment and drying of fruits and vegetables due to high drying speed, low energy consumption and preservation of heat sensitive compounds [22]. Combined microwave drying takes advantage of conventional drying methods and microwave heating, resulting in better processes than microwave drying alone [3]. Figure 1 shows the effect of microwave treatment time on the rate of moisture removal from carrot slices during the drying process. As can be seen, microwave treatment has increased the rate of moisture removal from the samples and thus reduced the drying time of the samples, and the drying time of the treated sample for 60 sec is shorter than other samples. The average drying time of samples treated with microwave for 0 (control), 15, 30, 45 and 60 sec was 225 min, 190 min, 160 min, 155 min, and 130 min, respectively. In line with the results of this research, Motevali, *et al.* [6] reported that the use of microwave pretreatment in drying pomegranate arils with a hot air dryer reduces the drying time compared to convective drying without pretreatment. The results of Motevali and

Hedayati [5] study also indicated a decrease in the drying time of apples by applying microwave pretreatment. Also, these researchers reported that the longest drying time for apples (345 min) was related to the control sample and the shortest drying time (75 min) was related to the sample pretreated with microwaves.

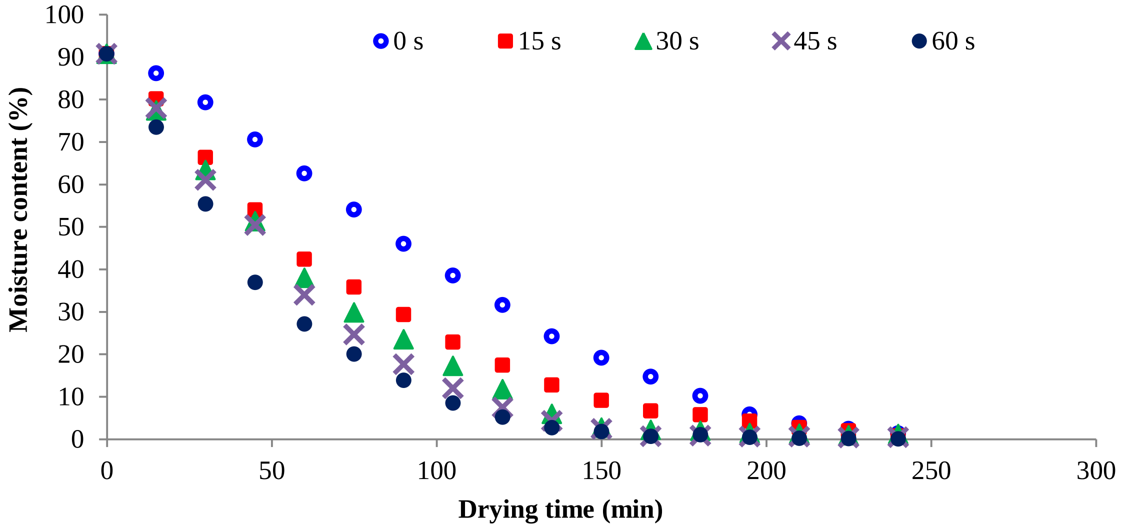

Figure 1- Effect of microwave pretreatment on the moisture content change of carrot slices during drying process

2-3- Results of genetic algorithm-artificial neural network modeling

Considering that the main goal of this study was to use artificial intelligence-based methods for modeling and optimization, genetic algorithm technique was chosen for optimization. In this study, different training algorithms were evaluated and Levenberg–Marquardt algorithm was selected as the best algorithm. Due to the lower error value obtained by using the sigmoid activation function, this type of function was chosen as the activation function in the hidden and output layer.

In artificial neural network, data sets are randomly classified into three sets including training, validating, and testing. Based on the trial and error method, it was determined that if 50% of the data is used for training, the network is well able to learn the relationships between inputs and outputs. 10% of the data was used for validating the trained network. In order to evaluate the network, the remaining data (40%) was used. The results of this research showed that the artificial neural network with 5 neurons in the hidden layer can well predict the moisture content of carrot slices treated with microwaves during the drying process.

[DOI: 10.22034/FSCT.20.145.139]

In this study, 6 indicators were used to evaluate the performance of the designed network, which included mean squared error, normalized mean squared error, mean absolute error, minimum absolute error and maximum absolute error. The error values and correlation coefficient for predicting the moisture percentage of carrot slices were reported in Table 1. The normalized mean square error for predicting the moisture percentage of carrot slices by the optimal neural network is equal to 0.006, which shows the power of the network in reducing the error during modeling. Also, the correlation coefficient calculated for predicting the moisture content of carrot slices by optimal neural network is equal to 0.997.

Table 1- The error values in prediction of moisture content of carrot slices during drying process

Error	Moisture content
Mean squared error	5.298
Normalized Mean squared error	0.006
Mean absolute error	1.620
Minimum absolute error	0.019
Maximum absolute error	8.768
Correlation coefficient (r)	0.997

Figure 2 shows the training data errors (mean square error) against the number of generations formed by the artificial neural network. In general, the error decreases after some training periods, and if the validation error increases, the training algorithm terminates. This figure shows that the amount of error has decreased in the first generations and after the formation of about 23 generations, the amount of error has reached a constant value, which shows the ability of the genetic algorithm method for optimization the parameters of the artificial neural network.

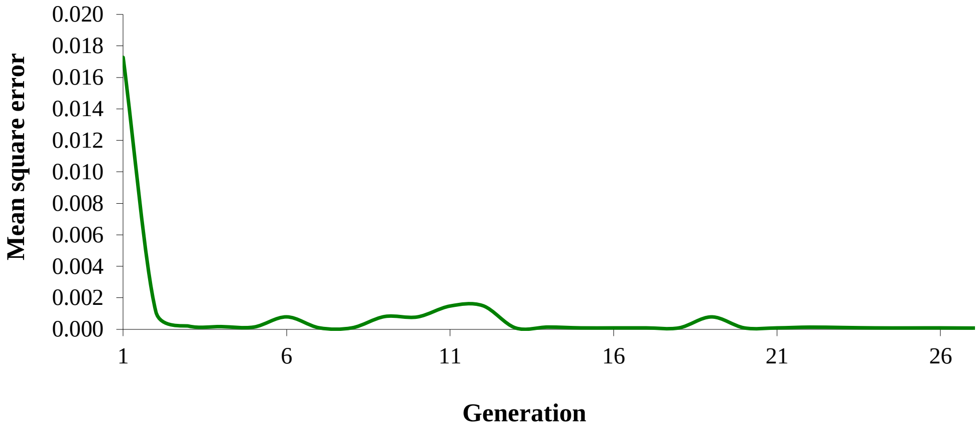

Figure 2- Mean square error versus generation during training of network

The genetic algorithm method is a search technique in computer science to find an approximate solution for mathematical model optimization and other problems that uses biological techniques such as inheritance, mutation and selection principles to find the optimal formula for predicting or matching the model [15]. The actual values of the testing data for the moisture percentage of the microwave-treated carrot slices during the drying process and predicted by the optimal genetic algorithm-artificial neural network (2-5-1) are shown in Figure 3. This figure shows the predicted data around the line of best fit (45°). The distribution of data in this graph shows the high efficiency of the genetic algorithm-artificial neural network method for modeling the drying process and predicting the moisture percentage of carrot slices.

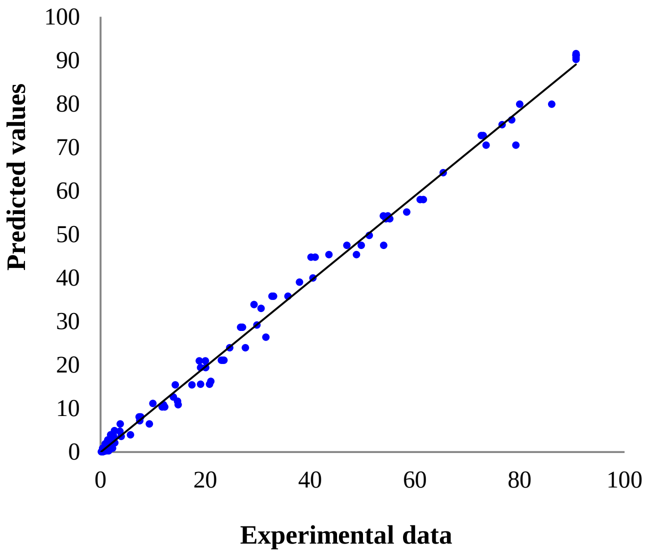

Figure 3- Experimental data vs predicted values of moisture content of carrot slices during drying process

The structure of an artificial neural network consists of an input layer consisting of input neurons (related to input variables), a hidden layer consisting of hidden layer neurons and an output layer consisting of output neurons (related to output variables) [23]. The goal of the genetic algorithm-artificial neural network training process is to obtain optimal neural network weight and bias values. Weights can be defined as the strength of connection between nodes that have very effective coefficients in converting input to output. To reduce the prediction error, the difference between the predicted response and the actual response is fed back to the network through the training algorithm,

[DOI: 10.22034/FSCT.20.145.139]

and the weights and biases are modified accordingly [15]. In Table 2, the values of weights and biases corresponding to each neuron for the network with 5 neurons in the hidden layer are reported. Regardless of the method used to select the hidden layer neuron range, the rule is always to select the network that performs best on the test set with the minimum number of hidden neurons [15, 24]. In the present study, the genetic algorithm optimized the structure of the artificial neural network well, and a network with five neurons in one hidden layer was the optimal network.

Table 2- Weight values and bias of the optimal network

Hidden neurons	Bias	Input neurons		Output neurons
		Microwave time (s)	Drying time (min)	Moisture content (%)
1	3.1931	-1.8347	-5.5813	3.2565
2	1.3420	-11.0719	-1.2530	0.5820
3	-1.4820	-1.3113	9.36109	-1.4665
4	0.3521	-0.6953	2.5041	-8.4074
5	-4.0259	-6.3299	-11.0761	-1.9877
Bias				6.8219

Sensitivity analysis of a system examines how sensitive the predicted variables (system outputs) are to independent input variables [15].

In the present study, in order to investigate the influence of input parameters and identify the most influential factor, a sensitivity analysis test was performed on the optimal network created by the genetic algorithm-artificial neural network method. As seen in Table 3, among the input variables, the length of the drying process is the most effective factor in predicting the content of carrot slices.

Table 3- Sensitivity analysis results for prediction of moisture content of carrot slices during drying process

Input parameter	Sensitivity
Microwave time (s)	3.467
Drying time (min)	13.158

4- Conclusion

In this study, the use of microwave pretreatment to increase the mass transfer rate during the drying process of carrot slices was investigated. By increasing the time of microwave treatment, intensity of treatment of the samples increased and the drying time of the samples was decreased. In this research, genetic algorithm-

[DOI: 10.22034/FSCT.20.145.139]

artificial neural network modeling was used to predict the moisture content of carrot slices during the drying process. Different training algorithms were evaluated and Levenberg–Marquardt algorithm was selected as the best algorithm. The genetic algorithm method had a high ability to find the optimal value of the network. The presence of 5 neurons in the hidden layer led to the highest r (correlation coefficient) and the lowest mean squared error, normalized mean squared error, and mean absolute error. Overall, the results of the research showed that the genetic algorithm-artificial neural network method is suitable for predicting the kinetics of carrot drying, and this method can be used to predict various kinetic parameters during drying process of fruits and vegetables. The results of the sensitivity analysis also showed that the drying process duration is the most effective factor in predicting the moisture content of carrot slices.

5- Acknowledgments

We acknowledge Bu-Ali Sina University Research Council for its financial support of this research.

References

[1] Salehi, F. 2023. Recent progress and application of freeze dryers for agricultural product drying, *ChemBioEng Reviews*. 10, 618-627.

[2] Kumar, C., Karim, M. A. 2019. Microwave-convective drying of food materials: A critical review, *Critical Reviews in Food Science and Nutrition*. 59, 379-394.

[3] Zhang, M., Tang, J., Mujumdar, A. S., Wang, S. 2006. Trends in microwave-related drying of fruits and vegetables, *Trends in Food Science & Technology*. 17, 524-534.

[4] Wray, D., Ramaswamy, H. S. 2015. Novel concepts in microwave drying of foods, *Drying Technology*. 33, 769-783.

[5] Motevali, A., Hedayati, F. 2017. Investigation of change drying rate constant coefficient in simulations models with various pretreatments on drying apple, *Innovative Food Technologies*. 4, 39-51.

[6] Motevali, A., Minaei, S., Khoshtagaza, M. H. 2011. Evaluation of energy consumption in different drying methods, *Energy Conversion and Management*. 52, 1192-1199.

[7] Tepe, F. B. 2022. Impact of pretreatments and hybrid microwave assisting on drying characteristics and bioactive properties of apple slices, *Journal of Food Processing and Preservation*. 46, e17067.

[8] Sharma, G. P., Prasad, S. 2006. Optimization of process parameters for microwave drying of garlic cloves, *Journal of Food Engineering*. 75, 441-446.

[9] Azadbakht, M., Vahedi Torshizi, M., Mahmoodi, M. J., Ghazagh Jahed, R. 2021. Mathematical modeling of the biochemical properties of carrots by microwave drying with different pretreatments using response surface methodology, *Food Engineering Research*. 21, 35-56.

[10] Karimi, S., Mohammadi, S., Layeghiniya, N., Abbasi, H. 2021. Effect of combined microwave-hot air under microwave pretreatment on drying kinetics of Myrtus fruit, *Journal of Food Processing and Preservation*. 13, 125-138.

[11] Simsek, M., Süfer, Ö. 2021. Influence of different pretreatments on hot air and microwave-hot air combined drying of white sweet cherry, *Turkish Journal of Agriculture-Food Science and Technology*. 9, 1172-1179.

[12] Aydar, A. Y. 2021. Investigation of ultrasound pretreatment time and microwave power level on drying and rehydration kinetics of green olives, *Food science and technology*. 41, 238-244.

[13] Najib, T., Heydari, M. M., Meda, V. 2022. Combination of germination and innovative microwave-assisted infrared drying of lentils: effect of physicochemical properties of different varieties on water uptake, germination, and drying kinetics, *Applied Food Research*. 2, 100040.

[14] Bassey, E. J., Cheng, J.-H., Sun, D.-W. 2022. Thermoultrasound and microwave-assisted freeze-thaw pretreatments for improving infrared drying and quality characteristics of red dragon fruit slices, *Ultrasonics Sonochemistry*. 91, 106225.

[15] Mousavikia, N., Mohammadi, F., Hasheminejad, H. 2022. Prediction and optimization of ultrasound-assisted removal of estrogen hormones from municipal wastewater using artificial neural network and genetic algorithm: a review approach, *Health System Research*. 18, 83-94.
[16] Salehi, F. 2020. Recent advances in the modeling and predicting quality parameters of fruits and vegetables during postharvest storage: A review, *International Journal of Fruit Science*. 20, 506-520.
[17] Satorabi, M., Salehi, F., Rasouli, M. 2021. The influence of xanthan and balangu seed gums coats on the kinetics of infrared drying of apricot slices: GA-ANN and ANFIS modeling, *International Journal of Fruit Science*. 21, 468-480.
[18] Parvaresh Rizi, A., Kouchakzadeh, S., Omid, M. H. 2006. Estimating moving hydraulic jump parameters by means of ANN and the integration of ANN and GA, *Iranian Journal of Agricultural Sciences*. 37, 187-196.
[19] Wei, Q., Lv, M., Wang, B., Sun, J., Wang, D. 2023. A comparative study of optimized conditions of QuEChERS to determine the pesticide multiresidues in Lycium barbarum using response surface methodology and genetic algorithm-artificial neural network, *Journal of Food Composition and Analysis*. 120, 105356.
[20] Lee, G. E., Kim, R. H., Lim, T., Kim, J., Kim, S., Kim, H.-G., Hwang, K. T. 2022. Optimization of accelerated solvent extraction of ellagitannins in black raspberry seeds using artificial neural network coupled with genetic algorithm, *Food Chemistry*. 396, 133712.
[21] Fadaie, M., Hosseini Ghaboos, S. H., Beheshti, B. 2020. Characterization of dried persimmon using infrared dryer and process modeling using genetic algorithm-artificial neural network method, *Journal of Food Science and Technology (Iran)*. 17, 189-200.
[22] Huang, D., Men, K., Tang, X., Li, W., Sherif, S. 2021. Microwave intermittent drying characteristics of camellia oleifera seeds, *Journal of Food Process Engineering*. 44, e13608.
[23] Zheng, Z.-Y., Guo, X.-N., Zhu, K.-X., Peng, W., Zhou, H.-M. 2017. Artificial neural network – Genetic algorithm to optimize wheat germ fermentation condition: Application to the production of two anti-tumor benzoquinones, *Food Chemistry*. 227, 264-270.
[24] Jin, L., Kuang, X., Huang, H., Qin, Z., Wang, Y. 2005. Study on the overfitting of the artificial neural network forecasting model, *Acta Meteorologica Sinica*. 19, 216-225.

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مقاله علمی_پژوهشی

استفاده از پیش‌تیمار مایکروویو برای افزایش سرعت انتقال جرم در طول فرآیند خشک‌کردن برش‌های هویج

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اطلاعات مقاله

تاریخ های مقاله :

تاریخ دریافت: ۱۴۰۲/۶/۱۷

تاریخ پذیرش: ۱۴۰۲/۷/۲۷

کلمات کلیدی:

آنالیز حساسیت،

الگوریتم ژنتیک–شبکه عصبی مصنوعی،

پرسپترون،

لونبرگ–مارکوارت،

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DOI: 10.22034/FSCT.20.145. 139

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چکیده

فرآیند خشک‌کردن یکی از روش‌های فرآوری سبزی‌ها و میوه‌ها است که باعث کاهش حجم محصول، تسهیل در حمل‌ونقل، افزایش قابلیت نگهداری و کاهش فعالیت‌های میکروبی می‌گردد. امواج مایکروویو به‌عنوان یک منبع گرمایش سریع و مؤثر با اثرات حرارتی و غیرحرارتی می‌تواند مستقیماً بر مواد غذایی تأثیر بگذارند و در نتیجه واکنش‌های فیزیکوشیمیایی و سرعت خشک شدن را تسریع و محصولات خشک‌شده با کیفیت بالا تولید کنند. هدف از این پژوهش استفاده از پیش‌تیمار مایکروویو برای افزایش سرعت انتقال جرم در طول فرآیند خشک‌کردن برش‌های هویج و مدل‌سازی فرآیند به روش الگوریتم ژنتیک- شبکه عصبی مصنوعی است. در این مطالعه اثرات زمان تیماردهی با امواج مایکروویو در پنج سطح ۰، ۱۵، ۳۰، ۴۵ و ۶۰ ثانیه بر زمان خشک شدن و محتوای رطوبت برش‌های هویج در سه تکرار مورد بررسی قرار گرفت. این فرآیند به روش الگوریتم ژنتیک- شبکه عصبی مصنوعی با ۲ ورودی (زمان تیماردهی با مایکروویو و طول فرآیند خشک‌کردن) و ۱ خروجی (درصد رطوبت) مدل‌سازی شد. نتایج نشان داد که با افزایش زمان تیماردهی با مایکروویو، سرعت خروج رطوبت از نمونه‌ها افزایش و در نتیجه زمان خشک‌کردن کاهش یافت. الگوریتم‌های آموزشی مختلف مورد ارزیابی قرار گرفت و الگوریتم لونبرگ–مارکوارت به‌عنوان بهترین الگوریتم انتخاب شد. بر اساس تحلیل‌های صورت گرفته روی داده‌های مدل‌سازی، شبکه عصبی مصنوعی پرسپترون با ساختار ۱–۵–۲ مناسب‌ترین شبکه برای پیش‌بینی محتوای رطوبت برش‌های هویج تیمار شده با امواج مایکروویو است. در این مطالعه مقادیر میانگین مربعات خطا (MSE)، میانگین مربعات خطا نرمالیزه شده (NMSE)، میانگین خطا مطلق (MAE) و ضریب تبیین (r) برای پیش‌بینی درصد رطوبت برش‌های هویج طی فرآیند خشک شدن به ترتیب برابر ۵/۲۹۸، ۰/۰۰۶، ۱/۶۲۰ و ۰/۹۹۷ بود. نتایج آنالیز حساسیت توسط شبکه عصبی بهینه نشان داد که طول فرآیند خشک‌کردن به‌عنوان مؤثرترین عامل در پیش‌بینی محتوای رطوبت برش‌های هویج بود.

[DOI: 10.22034/FSCT.20.145.139]