Journal of Food Science and Technology (Iran)

Homepage: www.fsct.modares.ir

Scientific Research

Modeling of microwave pretreatment effect on the oil extraction from tomato seeds by artificial neural network method

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ARTICLE INFO

Article History:
Received:2024/3/10
Accepted:2024/4/15

Keywords:

Artificial neural network.

Sensitivity analysis,

Tomato seed oil,

Microwave.

DOI: **10.22034/FSCT.21.152.181.**

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ABSTRACT

Increasing consumers demand for natural and additive-free foods and high volumes of food industry wastes, are stimulating the use of these resources in other food industries. Tomato pomace is one of the food factory wastes is the resulting by-product of tomato paste and sauce factories. The aim of this study was to evaluate the effect extraction method and microwave pretreatment of tomato seeds on the physicochemical characteristics of their extracted oil. The seeds were treated with microwaves using various power levels (0, 200 and 500 W) and different process times (0, 1, 3 and 5 min) and their oil was extracted by Soxhlet and press methods. Fatty acids composition of oils was determined by gas chromatography. Some physicochemical characteristics of extracted seed oil including oil yield, viscosity, acid value, peroxide value, and color index (L, b, a values) were evaluated. Data was analyzed with factorial treatment structure in a Completely Randomized Design in three replications. The experimental data was modeled by artificial neural network with 3 inputs (extraction method, microwave power and pretreatment time) and 7 outputs (oil yield, acid value, peroxide value, viscosity, L value, b value and a value). The results of artificial neural network modeling showed that the network with a 3-8-7 structure and using the Hyperbolic tangent activation function can predict the oil yield, acid value, peroxide value, viscosity, L value, b value and a value of tomato seed oil with high correlation coefficient and low error. Based on the results of the sensitivity analysis, the extraction method compared to the power and time of microwave assisted pretreatment of seeds was determined as the main factor.

1-Introduction

Food wastes are byproducts of biological materials that are used to food production. The processing of these wastes with the aim of obtaining their effective compounds for use in the food industry has been considered. Among the methods of food waste processing is the extraction of bioactive compounds such as oils, proteins and dyes [1]. Useful and fast processing of waste from various industries, including the food industry, is effective in reducing the emission of greenhouse gases and produced waste [2]. Tomato (*Solanum lycopersicum L*) is a widely consumed and popular product with an annual production of more than 241 million tons in the world. 80% of all tomatoes produced in the world are consumed fresh and 20% processed (paste, sauce and pickle) [3]. Tomato pomace is a waste product during tomato processing, which consists of three parts: flesh (40%), skin (27%) and seeds (33%) [4]. Tomato seeds contain nutritious compounds such as edible oil, protein and lycopene [5]. Extraction is the main process of oil production from oilseeds, which is usually done by two methods: pressing (applying mechanical pressure on oilseeds) or soxhlet (saturating the solvent with the oil in the oilseed) [6]. Extraction of oil by press is simpler, safer, less expensive and less efficient compared to solvent. Oil extraction with Soxhle (hexane solvent) is associated with obstacles such as long process time, high cost, release of volatile organic compounds into the environment and to some extent the quality of the oil produced [7]. One of the main obstacles to the extraction of oil seeds with solvent is the remaining solvent in the oil, which has a negative effect on the health of the consumer. Recently, the use of oils produced by the press method has received attention due to the tendency of people to consume healthy foods with minimal processing [8]. The use of new pretreatments, including microwaves, with the aim of increasing the extraction efficiency, improving the physical and chemical quality, and increasing the shelf life of oilseeds (chia seeds, rapeseeds, flax seeds, thistle seeds, black seeds) has attracted a lot of attention. has attracted [9]. Microwaves (frequency 300 MHz to 300 GHz) are in the group of non-ionizing electromagnetic waves. The principles of microwave heating are the direct effect of waves on polar materials through the two phenomena of ion transfer and dipole rotation [10]. Artificial neural network as a powerful tool plays an important role in predicting and modeling the parameters of food processes. The first mathematical model of artificial neuron was initially proposed by McCullock and Pitts [11]. A neural network is a set of building units called neurons. An artificial neuron is also composed of a preliminary processing unit with several inputs and one output. Neuron inputs can be outputs of other neurons or simple external outputs. An output from a nerve cell can also be an input to several other nerve cells [12]. The purpose of using simulation or modeling in processes is actually to convert physical qualities and the mutual relationship of these qualities into numerical quantities and mathematical relationships. A model consists of variables and a set of equations related to them, which shows the mutual influence of these variables in the real world [13]. The artificial neural network has the ability to simulate the basic processes of the biological nervous system to deal with external factors. Genetic Algorithm is inspired by nature and is formed on the basis that the fittest have the right to survive. Genetic algorithm optimization method can be used to overcome the inherent limitations of artificial neural network. The combined genetic algorithm-artificial neural network method is widely used to model food processes and predict desired parameters in the design and development of systems [14]. Using artificial neural network in modeling and predicting various food processes such as drying, osmotic dehydration, extracting effective substances such as lycopene from tomato pulp, soaking seeds, modeling the process of freezing and unfreezing, and extracting oil from seed oils have been used [15]. Considering that no research has been done in the field of modeling oil extraction from tomato seeds with the help of microwave pretreatment, therefore the aim of this study is to achieve a simple, fast, accurate and efficient model using a network. Artificial neural networks were related to the effect of microwave pretreatment and tomato seed oil extraction method on the physical and chemical characteristics of the resulting oil.

2- Materials and methods

2-1- Tomato seed purification

Tomato pulp was obtained from a tomato paste factory (**Fig. 1**). The separation of seeds from pulp was done according to Zoro et al.'s method (2013) with some changes [16]. The waste was immersed in a large plastic container filled with water. Due to the difference in the density of seeds with water and scum, the seeds were deposited at the bottom of the container and the rest of the scum was placed on the surface of the water (**Fig. 1**). The isolated seeds were kept dry at laboratory temperature (25°C) for 6 hours in moisture and oxygen resistant bags. All the chemicals used were of laboratory type, which were obtained from Merck, Germany.

(a)

(b)

Fig.1. Tomato pomace (a) and Tomato seeds sedimentation (b)

2-2- Microwave pretreatment of tomato seeds

80 grams of tomato seeds were distributed in a thin layer with a diameter of about 30 mm on the surface of a microwave-resistant Pyrex glass container and placed in a 50-liter laboratory microwave oven (NN-C2002W, Japan). The samples were subjected to microwave radiation at two power levels of 200 and 500 watts for 1, 3 and 5 minutes, respectively, and after cooling at the laboratory temperature (25°C) in plastic bags with fabric cover. They were kept at laboratory temperature until the stage of oil extraction. The tomato seeds that were not exposed to radiation were used as a control sample [17].

2-3- Seed oil extraction by press method

Tomato seed oil (80 grams) was extracted at a temperature of 35°C for 10 minutes with a single spiral mini press (Bekordane, Iran) at a speed of 20 rpm according to the

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method of Yilmaz and Gonser (2017) with some modifications. [18].

2-4- Seed oil extraction by Soxhlet method

Tomato seed oil (80 grams) was extracted using an automatic Soxhlet machine with n-hexane solvent (Merck, Germany) and the standard method of the World Grains and Seeds Association (AACC Approved Methods of Analysis 30-25.01) with some modifications. became [19].

2-5- Tomato seed oil evaluation

2-5-1- Oil extraction efficiency

The oil extraction efficiency was calculated by dividing the weight of oil extracted from the seeds by their initial weight [20].

2-5-2- Acid value

The acid value of the extracted oil was determined according to the standard method (AOAC, 969.17 Method, 2005) [21]. 5 grams of oil were dissolved in 25 ml of ethanol and ether mixture and neutralized with 0.1 normal potassium hydroxide in the presence of phenolphthalein until a pink color appeared. The acid number (mg of potassium hydroxide required to neutralize free fatty acids in one gram of oil sample) was calculated according to the formula (Acid value = $(V \times N \times 56.1)/m$). (N) is the normality of potassium hydroxide, (V) is the volume of potassium hydroxide in milliliters, and (m) is the weight of the oil sample in grams.

2-5-3- Peroxide value

The peroxide value of the extracted oil was measured according to the standard method (AOAC, 965.33 Method, 2005) [21]. About 5 grams of oil was added to 30 ml of acetic acid-chloroform solution (volume ratio 3:2) and mixed. 0.5 ml of saturated potassium iodide solution was added to it and placed in a dark environment for about one minute. After adding 30 ml of distilled water, 0.01 normal sodium thiosulfate was added to the solution until the yellow color disappeared. About half a milliliter of 1% starch glue was added to the solution and the addition of sodium thiosulfate continued until complete neutralization (disappearance of blue color). The control sample went through the mentioned steps as a sample without oil. The oil peroxide number (milliequivalent grams of oxygen per kilogram of oil) was calculated based on the formula (Peroxide value = $(N(s-b))/W \times 1000$). (N) is the normality of sodium thiosulfate, (S) is the volume of thiosulfate used in milliliters, (b) is the volume of thiosulfate used in milliliters, and (W) is the weight of the oil sample in grams.

2-5-4- Oil viscosity

The viscosity of tomato seed oil samples at 25 degrees Celsius was measured using a Brookfield viscometer (Brookfield-DV2T) equipped with an adapter (UL) and using a cylindrical spindle (SC4-21) and measured in traditional units. Poise was reported [22].

2-5-5- Oil color

Image processing method was used in color evaluation. About 10 ml of each oil sample was poured into a glass petri dish (diameter 5 cm) and photographed with the help of a camera (Canon, Japan) at a fixed distance of 20 cm. First, the images were saved in JPG format and in RGB color space. Images taken by Image J software (Image J software version 1.42e, USA) and its program (Color-Space-Converter) from RGB color space to color components of brightness (L value), red-green (a value) and yellow- They became blue (b value) [23].

2-6- Statistical analysis

This research is based on the factorial method and according to a completely random statistical design with three factors of microwave pretreatment power (0, 200 and 500 watts), time (0, 1, 3 and 5 minutes) and the type of extraction method (cold press and Soxhlet) tomato seed oil was done in three replicates. Data analysis was done

[DOI: 10.22034/FSCT.21.152.181]

with statistical software (SPSS) and averages were compared based on Duncan's multi-range test at a significance level of 5%.

2-7- Genetic algorithm modeling - artificial neural network

Modeling of the process of tomato seed oil extraction to predict extraction percentage, acid number, peroxide number, viscosity, brightness, redness and yellowness was done by genetic algorithm-artificial neural network method, by three-layer feedforward perceptron neural networks. 3 inputs (extraction method, microwave power and treatment time) and 7 outputs (extraction percentage, acid number, peroxide, viscosity, brightness, redness and yellowness) were considered. Neurosolution software (version 5) was used for modeling. In this software, by changing the type of activation function (linear, sigmoid and hyperbolic tangent); The number of data used for learning, testing and evaluation and Lönberg-Marquardt learning rule, the best network structure to achieve the optimal network were investigated. In order to evaluate the neural network used to predict the investigated parameters, correlation coefficient index was used [24].

3-Results and discussion

3-1-Results of genetic algorithm-artificial neural network modeling

Due to the fact that the structure of the artificial neural network model is formed by using collected experimental data, it has good ability and accuracy in predicting and displaying data [25]. In this study, extraction method, microwave power, and treatment time were considered as network inputs, and extraction percentage, acid value, peroxide, viscosity, brightness, redness, and yellowness were also selected as network outputs. Due to the lower error value obtained by using the hyperbolic tangent activation function, this type of function was selected as the activation function in the hidden and output layer. 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 (Table 1). 20% of the data was used for testing the trained network and 30% of the data was used for evaluating the network. The results showed that the artificial neural network with 8 neurons in the hidden layer can well predict the extraction percentage, acid number, peroxide, viscosity, brightness, redness and yellowness of the oil prepared from tomato seeds. The results of the error values calculated by the optimal network showed that the neural network with the 7-8-3 structure with the hyperbolic tangent activation function with a high correlation coefficient and low error value compared to other network structures has better results for predicting the properties of the oil extracted from the seeds. provides tomatoes (Table 2). In another research, the modeling of oil extraction from sunflower seeds using artificial neural network model has been investigated by Bakhshabadi colleagues (2017). In this research, the process of oil extraction using artificial neural networks with two input vectors (temperature and grain moisture) and five output vectors (amount of oil, moisture and meal protein and the percentage of fine matter insoluble in oil and oil acidity) is modeled and the results obtained from Artificial neural network is compared with experimental data. The best result was obtained by the back-propagation neural network with topology 2-5-10 and correlation coefficient greater than 0.99 and with Lunberg-Marquardt training algorithm and hyperbolic tangent activation function, which indicated the high accuracy of the artificial neural network. Sánchez et al. (2017) by examining different pretreatments (microwave and hydrothermal) of rapeseed before extraction using artificial neural network model compared to other models reported

[DOI: 10.22034/FSCT.21.152.181]

that the presented model can be a very powerful substitute for Other statistical models are related to oil extraction kinetics [26].

Table 1. The optimal values of artificial neural network

Hidden layers	Algorithm	Activation function	Hidden neurons	Training (Percent)	Validation (Percent)	Testing (Percent)
1	Levenberg–Marquardt	Hyperbolic Tangent	8	50	20	30

Table 2. The error values in prediction of the quality parameters of tomato seed oil (testing data) by optimal artificial neural network with 8 neurons in hidden layer

Error	Extraction efficiency	Acid value	Peroxide value	Viscosity	L value	b value	a value
Mean squared error (MSE)	1.97	0.31	0.16	1.31	10.78	0.07	3.75
Normalized Mean squared error (NMSE)	0.12	0.32	0.06	0.25	0.15	0.40	0.10
Mean absolute error (MAE)	0.92	0.43	0.33	0.89	2.58	0.23	1.61
Minimum absolute error	0.16	0.01	0.02	0.13	0.38	0.03	0.13
Maximum absolute error	3.47	0.91	0.48	2.42	6.36	0.42	2.89
Correlation coefficient (r)	0.97	0.83	0.98	0.94	0.96	0.80	0.97

The average value of the squared error against the number of formed generations is shown in **Fig. 2**. In the early generations, the trend of reducing the number of errors was observed, and after about 37 generations, the amount of error reached a constant value, which shows the ability of the genetic algorithm method to optimize the parameters of the artificial neural network.

[DOI: 10.22034/FSCT.21.152.181]

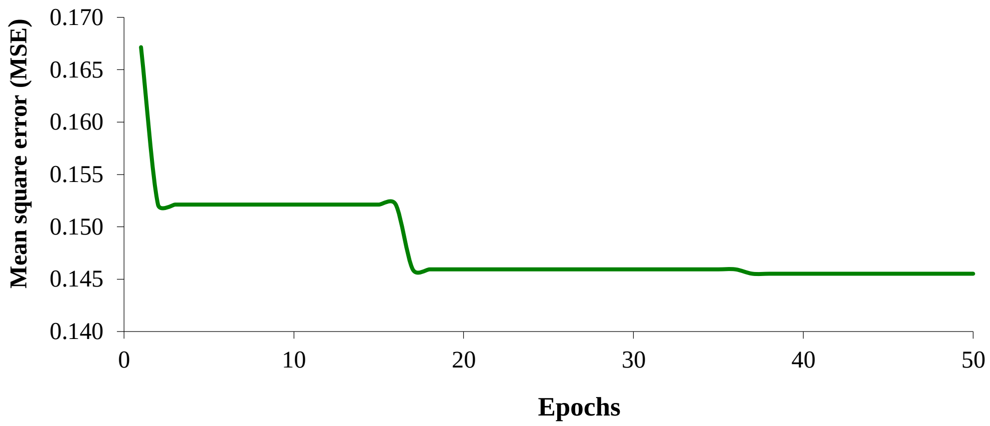
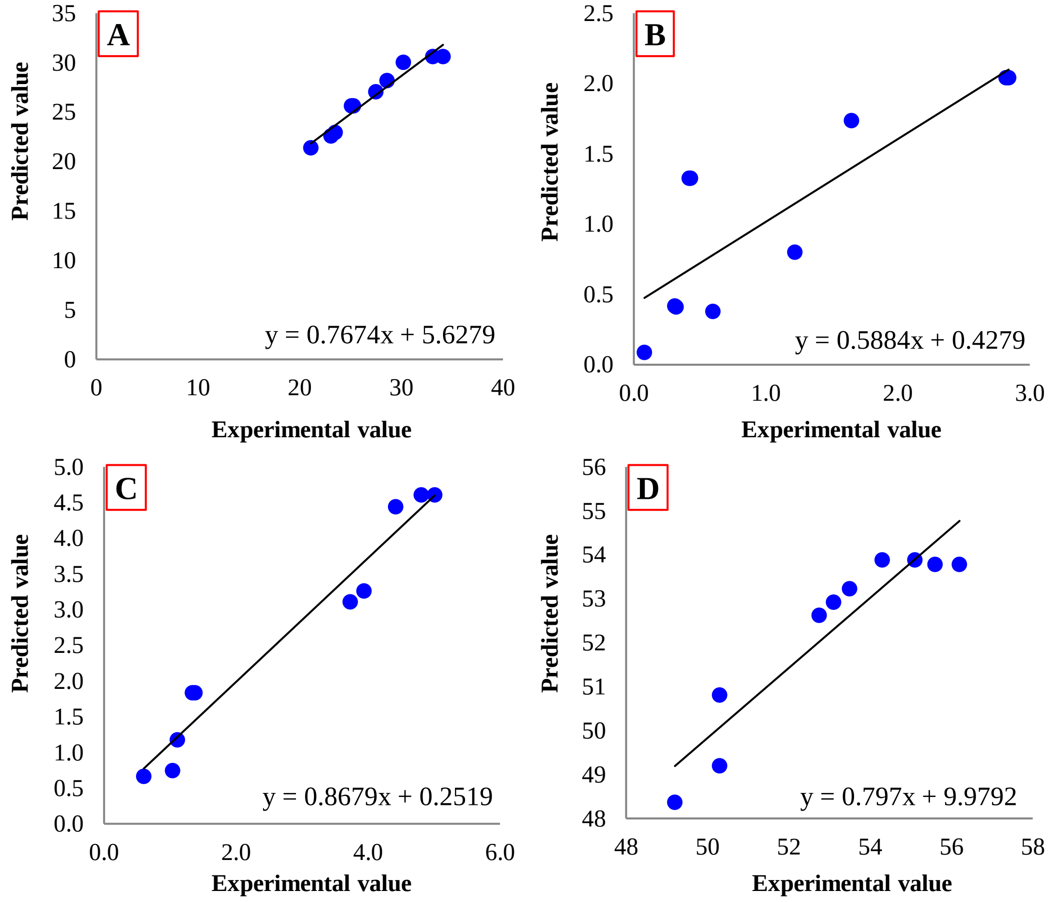


Fig. 2. Variations of mean squared error (MSE) versus epoch during the training of the optimal network

The actual values of the evaluated and predicted data for extraction percentage, acid number, peroxide, viscosity, brightness, redness and yellowness of the oil prepared from tomato seeds, by the genetic algorithm-optimized artificial neural network (3.7.8) are shown in **Fig. 3.**



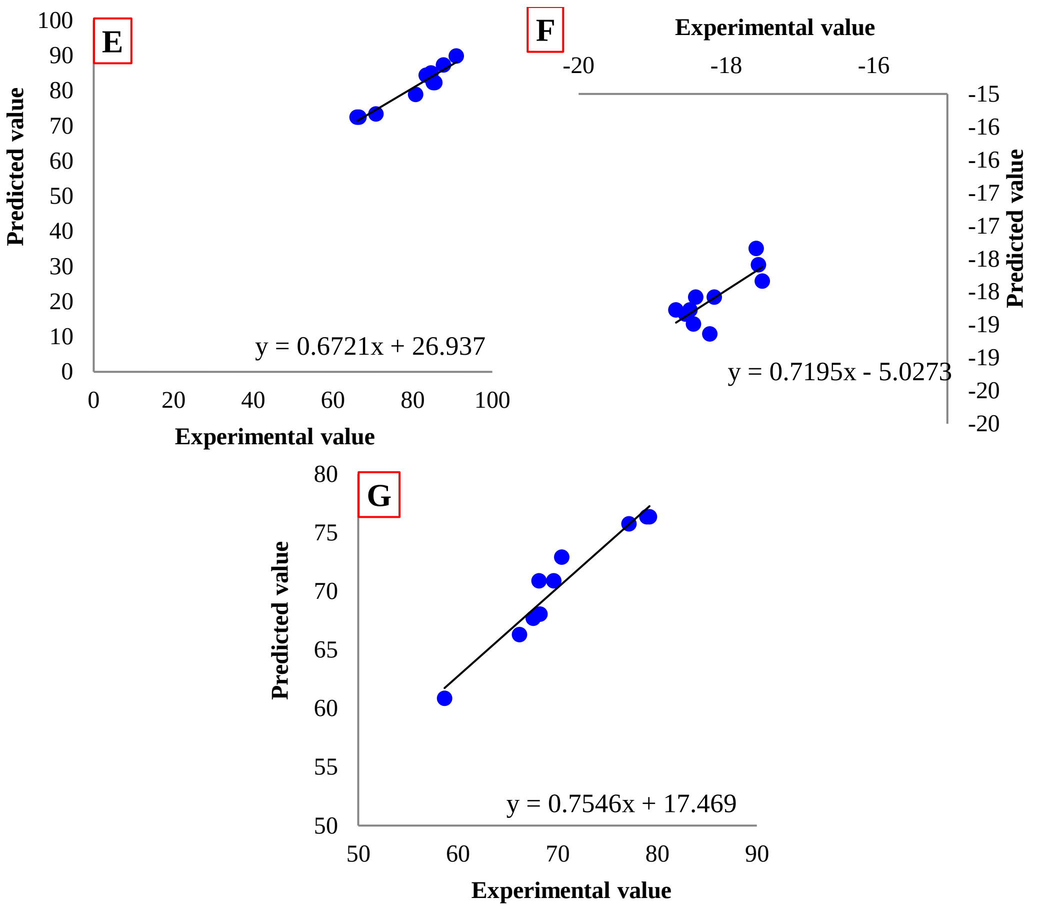


Fig. 3. Plot showing experimental values and ANN predicted values for Extraction efficiency (A), Acid value (B), Peroxide value (C), Viscosity (D), L value (E), a value (F), and b value (G) of tomato seed oil

Karmi et al. (2022) predicted the extraction of essential oil from yarrow plant using artificial neural network as a combination of one or two hidden layers with different functions with 4 to 30 neurons for modeling by perceptron neural network and report showed that both Lunberg-Marquardt backpropagation and Bayesian regularization algorithms have the ability to predict essential oil extraction performance with high accuracy [27]. Lozaich et al. (2021) used artificial neural network to model oil extraction from sunflower hybrid seeds and announced that this developed model has good generalization ability to predict mechanical oil extraction performance of sunflower hybrid seeds. In this research, a network with the number of 15 neurons in the hidden layer of a feedforward network (1-15-16) and using the hyperbolic tangent activation function and the amount of data used for training, testing and evaluation is equal to 20, 20 and 60 percent. used. The coefficient of explanation of the artificial neural network for predicting the percentage of oil extraction was equal to 0.997 [28]. Suryavanshi and Mohanty (2018), analyzed the modeling of oil extraction by critical fluid method from Mexican anemone seeds with artificial neural network. The results of predicting the amount of oil extraction by the neural network with one hidden layer and five input layers (temperature, pressure, particle size, input carbon dioxide flow rate and amount of solvent aid) showed that the best network with the lowest sum of squared error is 0.0038 and the highest average regression coefficient of 0.9838 was the optimization method of Levenberg-Marquardt [29]. Moghimi et al. (2017) by examining different networks, feedback propagation network with topology (2-8-6) and with correlation coefficient greater than 0.999 and mean square error less than 0.001 by using sigmoid activation function , reported the jump learning model and 1000 learning cycle as the best neural model. The reason for using these models was to optimize and control the process with the aim of saving energy and time and achieving a high-quality product [30]. The goal of the genetic algorithm-artificial neural network training process is to obtain optimal neural network weight and bias vectors. In Table 3, the values of weights and biases corresponding to each neuron for the network with 8 neurons in the hidden layer are reported.

Table 3. The weight and bias values of optimal neural network

Hidden neurons	Bias	Impute neurons			Output neurons						
		Extraction method	Power	Time	Extraction efficiency	Acid value	Peroxide value	Viscosity	L value	b value	a value
1	0.462	0.003	1.498	1.449	0.325	0.053	0.084	0.647	0.364	0.543	-0.509
2	0.522	-0.393	-0.526	-0.322	-0.050	0.664	0.066	0.099	0.827	0.569	0.149
3	0.300	0.8252	-0.217	0.205	0.117	0.351	0.292	0.092	-0.771	-0.055	1.027
4	-0.283	-0.212	-0.284	0.059	-0.127	0.006	0.466	0.418	0.467	0.203	-0.261
5	0.931	-0.072	-0.495	0.982	1.235	-0.026	0.905	0.550	-.0591	-0.401	0.673
6	0.306	-0.257	0.299	0.433	-0.327	-.0.843	-0.238	-0.554	-0.279	0.228	-0.510
7	0.014	1.021	0.049	-0.105	0.004	0.114	-0.411	0.205	-1.272	-0.768	-0.540
8	-0.606	-1.127	0.085	1.046	0.273	-0.258	-0.417	1.140	0.203	-.0.358	-0.532
Bias					-0.253	-0.543	-0.415	-0.294	0.418	0.204	-0.904

3-2- Sensitivity analysis

Sensitivity analysis is a practice to determine the amount and distribution of input data with the greatest impact on the output of the model. In fact, by analyzing the sensitivity of the input parameters, it reduces the trial and error stages and identifies the most important parameters affecting the desired phenomenon [31]. Sensitivity analysis is a powerful tool that by providing new skills to artificial neural network models increases the efficiency of the model in different fields of decision making, operational processes and optimization [32]. In this research, in order to investigate the influence of the 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. According to Figure 4, compared to all the input variables, the method of oil extraction from tomato seeds was determined as the most effective factor in changing the parameters of extraction percentage, acid number, peroxide, viscosity, brightness, redness and yellowness. In research by Ezni Eshri et al. (2014) to predict the synthetic parameters

[DOI: 10.22034/FSCT.21.152.181]

of fish oil oxidation in the presence of different concentrations of antioxidants and at different temperatures, using a multilayer perceptron artificial neural network with two inputs (temperature and concentration) and three outputs. (antioxidant, antioxidant activity and oxidation rate ratio) were used, and the optimal model with 7 neurons in the hidden layer showed the best agreement with the experimental data. Also, the results of the sensitivity analysis of the optimal model indicated the high sensitivity of the kinetic parameters, especially the antioxidant activity, to the concentration parameter due to the high antioxidant activity of methyl gallate and the lack of participation in side reactions in the diffusion phase [33].

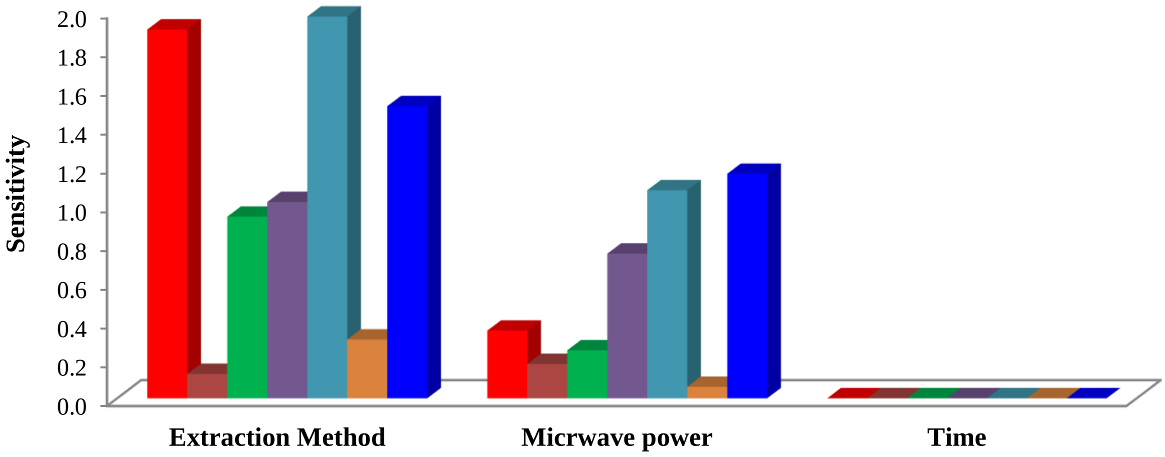


Fig. 4. Sensitivity analysis results of tomato seed oil extraction

4- Conclusion

Tomato seed oil is known as an edible oil with very high nutritional quality. The purpose of this research was to model the effect of microwave pretreatment and extraction method on some physical and chemical characteristics of tomato seed oil. Genetic algorithm-artificial neural network modeling was used to predict extraction percentage, acid number, peroxide, viscosity, brightness, redness and yellowness of oil prepared from tomato seeds as a function of extraction method, microwave power and microwave treatment time. The modeling results showed that the genetic algorithm-artificial neural network method is suitable for predicting the characteristics of the oil extracted from tomato seeds and this method can be used to predict the process parameters. The results of the sensitivity analysis also indicated that the extraction method is the most effective independent variable in determining the characteristics of oil extracted from tomato seeds.

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مقاله علمی_پژوهشی

مدل‌سازی اثر پیش‌تیمار مایکروویو براستخراج روغن از دانه‌های گوجه‌فرنگی به روش شبکه عصبی مصنوعی

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اطلاعات مقاله

تاریخ های مقاله :

تاریخ دریافت: ۱٤۰۲/۱۲/۲۰

تاریخ پذیرش: ۱٤۰۳/۱/۲۷

کلمات کلیدی:

آنالیز حساسیت،

شبکه عصبی مصنوعی،

روغن دانه گوجه‌فرنگی،

مایکروویو.

DOI:10.22034/FSCT.21.152.181.

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چکیده

افزایش تقاضای مصرف‌کنندگان برای استفاده از مواد غذایی طبیعی و بدون افزودنی و همچنین افزایش ضایعات صنایع غذایی، محرک استفاده از محصولات جانبی کارخانه‌های مواد غذایی در دیگر صنایع غذایی است. تفاله گوجه‌فرنگی ازجمله ضایعات کارخانه‌های مواد غذایی است که در کارخانه‌های تولید رب و سس از گوجه‌فرنگی تولید می‌شود. هدف از این پژوهش بررسی اثر پیش‌تیمار مایکروویو و روش استخراج بر ویژگی‌های فیزیکی و شیمیایی روغن دانه گوجه‌فرنگی بود. پیش‌تیمار دانه‌ها با امواج مایکرویو (۰، ۲۰۰ و ۵۰۰ وات) طی زمان‌های مختلف (۰، ۱، ۳ و ۵ دقیقه) انجام و روغن دانه‌ها با روش سوکسله و پرس استخراج گردید. برخی ویژگی‌های فیزیکی و شیمیایی روغن استحصالی شامل بازده استخراج، ویسکوزیته، عدد اسیدی، عدد پراکسید، و مؤلفه‌های رنگی شامل روشنایی، قرمزی و زردی ارزیابی گردید. تجزیه و تحلیل داده‌ها بر اساس آزمایش فاکتوریل در قالب طرح آماری کاملاً تصادفی در سه تکرار انجام شد. داده‌های آزمایشگاهی این پژوهش توسط روش الگوریتم ژنتیک- شبکه عصبی مصنوعی با ۳ ورودی (روش استخراج، توان مایکروویو و زمان تیماردهی) و ۷ خروجی (درصد استخراج، عدد اسیدی، عدد پراکسید، ویسکوزیته، روشنایی، قرمزی و زردی) مدل‌سازی شد. نتایج مدل‌سازی به روش الگوریتم ژنتیک- شبکه عصبی مصنوعی نشان داد شبکه‌ای با ساختار ۷-۸-۳ در یک لایه پنهان و با استفاده از تابع فعال‌سازی تانژانت هیپربولیک می‌تواند درصد استخراج، عدد اسیدی، عدد پراکسید، ویسکوزیته، روشنایی، قرمزی و زردی روغن تهیه‌شده از دانه‌های گوجه‌فرنگی را با ضریب همبستگی بالا و مقدار خطا پایین پیش‌بینی نماید. بر اساس نتایج آزمون آنالیز حساسیت، روش استخراج در مقایسه توان و زمان پیش‌تیمار دانه‌ها با مایکرویو، به‌عنوان عامل اصلی تعیین گردید.