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Scientific Research

Determining the appropriate model of red onion drying kinetics and comparing mathematical models of Neuro-Fuzzy Inference System (ANFIS)

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ABSTRACT

In this research, The kinetics of drying, The Determining The effective Moisture Diffusivity, Activation Energy, And also the prediction of the moisture ratio of red onion during the dry process with dryer-hot air drying were carried out with the help of mathematical models and fuzzy neural inference system (ANFIS). The experiments were performed at four levels of temperature at 50, 60, 70 and 80 0C and a constant air flow rate of 1 m/s . To select a suitable drying model, twelve thin layer drying models were used, as well as using fuzzy neural inference system R Software version 3.6.2. The results showed that among the mathematical models, The binomial model with the highest coefficient of explanation and the lowest root mean square error was the most suitable. The results of the correlation coefficient value (R2 = 0.999 and error) RMSE = (0.002) the lowest root mean square error It predicted the humidity ratio better than mathematical models.Effective Moisture Diffusivity for four temperatures (40,50,60 and 70° C), were (0.03136255,0 0211698,00193770.001847669 0) m^2/s Respectively andThe amount of activation energy was 1890 (kJ /(kg.K)).

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1- Introduction

Red onion has about 89% water, 4% sugar, 1% protein, 2% fiber and 0.1% fat and has 166 kJ (40 kcal) of energy per 100 grams. Red onion is consumed fresh and dry. Dried onion is used as an additive and flavoring in food [1]. Onion has a high nutritional value and is a very important and useful source in the diet for body health [2]. Drying is the most common process to preserve agricultural products [3]. In drying methods, factors such as temperature and air velocity, initial and final humidity of the product, relative humidity, ambient air temperature, and depth of the food are effective on the amount of moisture changes with respect to time, or drying kinetics [4]. The purpose of mathematical modeling in the process of drying agricultural products and food industries is actually to convert the physical qualities and the mutual relationship of these qualities into numerical quantities and mathematical relationships. In mathematical models, variables and sets of dependent equations show their mutual influence in the real world. This method is very suitable for predicting changes. Fuzzy neural inference system (ANFIS) is one of the most important methods of artificial intelligence that have successfully operated in natural processes by evaluating and asking questions in these processes. Anfis is superior to many statistical methods and performs better compared to regression models for predicting real data changes [5]. In a research, onion drying kinetic modeling was done in a fluidized bed dryer equipped with a humidity controller. Thin onion slices were dried in a laboratory dryer with three temperatures of 40, 50 and 60 ºC and two air speeds of 2 and 3 m/s in constant air humidity. In order to model drying kinetics, artificial neural networks were used for modeling. Correlation coefficient of 0.99956 and mean square error of 0.000039385 were presented as the best neural model by using hyperbolic sigmoid tangent activation function, Lunberg-Marquette learning model and 1000 APCH learning cycle. In general, it can be said that the combination of fuzzy logic principles and artificial neural networks is a suitable and reliable method for modeling and predicting the drying kinetics of onions and similar products [6]. In a research, prediction of white berry drying kinetics and comparison between mathematical models, artificial neural networks and Anfis were done. Drying of the product was done at three temperatures of 55, 40 and 70 ºC, three air flow speeds of 0.5, 1 and 1.5 m/s and three microwave powers of 270, 450 and W630. In order to select a suitable drying curve, ten models of thin drying layers, artificial neural networks and ANFIS were fitted with the laboratory data. The results showed that the MSE mean square error values for the mathematical model, ANN and ANFIS were 0.0052 and 0.0059, respectively. 0/0 and 0/0044 were obtained. Therefore, the ANFIS model with the highest correlation coefficient value (R 0.9999)^2 = (and the mean square error (0.0044) MSE = was chosen as the best model to evaluate the humidity ratio in comparison with other methods implemented in this research) [7]. Drying the thin layer of dark red onion at different temperatures of 50, 60 andthC 70 and it was done at four air flow speeds (2, 3.6, 5.7 and 7.7) meters per second. The value of the effective diffusion coefficient increased with the increase of drying air temperature and air speed. Arithmetic mean values of effective diffusion coefficient and activation energy were within the range of agricultural products [8]. Many researches have successfully used mathematical and elegant models to describe the drying of agricultural and food products [9]. The aim of this research is to investigate the drying kinetics of red onion at temperatures of 50, 60, 70 and^{ºC}80, drawing its drying curves and determining the activation energy and effective diffusion coefficient at test temperatures. Also, determining the appropriate model of red onion drying among 12 mathematical models and fuzzy neural inference system (ANFIS).

2- Materials and methods

Red onion was procured from Tarebar field in Ray city of Tehran province and after that, the onions were transferred to the laboratory refrigerator at a temperature of 5 degrees Celsius until the start of the experiment. The relative humidity of the air was done through the bubble test and was determined from the psychrometric table. Onion samples were cut into pieces by a slicer model (V-Rendesi). To carry out this research, a dryer with a volume of 12 cubic feet, manufactured by Grok Engineering Company of Iran, was used in the Biosystems Engineering Laboratory located in the Sheikh Bahai Laboratory Complex, in the Science and Research Unit of Islamic Azad

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University, and using a Japanese digital scale (AND- EK-600) and with an accuracy of 0.001 gr± The samples were weighed. Experiments were conducted in the form of a completely randomized design in three replications with factorial testing and were analyzed with the help of R software.

2-1- Preparation of samples

Before the test, the red onion samples were taken out of the refrigerator and cut into 4 mm thick pieces. Samples and test containers were weighed and recorded. Dryer 30 minutes before the start of the test at the test temperature, which includes four temperature levels (50, 60, 70,℃ 80) and the constant air speed was 1 m/s. Red onion moisture was measured before and after drying. The samples were dried in a thin layer and at 10-minute intervals, the test samples were removed from the dryer and weighed using a digital scale to record weight changes during the process. The drying tests were carried out until the moisture content of the product reached 20%. Dry weight basis continued.

MR moisture ratio of red onion is obtained using equation (1):

$MR=M_t-M_{It\ is}/ M_0-M_{It\ is}$(1)

where MR is the dimensionless moisture ratio, M_t The moisture content of the product at any time, $M_{It\ is}$ Equilibrium moisture content and M_0 is the initial moisture content. For long periods of time, $M_{It\ is}$ In comparison with the values of M_0 and M_t is very small, so the equation of moisture ratio during drying can be written as equation (2) [10].

$MR = M_t / M_0$ (۲)

The moisture evaporation rate of red onion was calculated using equation (3) [11].

$DR= M.Sc_{t+\Delta t} /\Delta t$ (3)

In order to investigate the kinetics and predict the drying process of red onion, 12 different thin layer drying models were used according to Table (1).

Table 1 Models used to investigate the Red onion thin layer drying

Model	Model Name	References
$MR=\exp(-kt)$	Newton (lewis)	**[12]**
$MR=a \exp(-(kt)^n) +b$	Demir et al	**[13]**
$MR=\exp(-(at/(1+b)))$	Aghbashlo	**[14]**
$MR=\exp(-kt^n)$	Page	**[15]**
$MR=\exp(-(kt)^n)$	Modified Page	**[16]**
$MR=a\exp(-kt)$	Henderson &Pabis	**[17]**
$MR=a\exp(-kt)+(1-a)\exp(-kat)$	Two term exponential	**[18]**
$MR = 1 +at+bt^2$	Wang & sing	**[17]**
$MR=a\exp(-kt)+(1-a)\exp(-kbt)$	Diffusion approximation	**[18]**
$MR=a\exp(-kt)+c$	Logaritmic	**[19]**
$MR=a\exp(-k_1t)+b\exp(-k_2t)$	Two term	**[18]**
$MR=a\exp(-kt^n)+bt$	Midili et al	**[20]**

The statistical indicators listed in Table 2 were used to evaluate the models.

Table 2 Models evaluation indices

Index		Reference
$x^2 = \sum_{i=1}^{N} \frac{(m_{P_i} - m_i)^2}{N-n}$	Chi-square (x^2 x^2)	[21]
$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(m_i - m_{P_i})}{N}}$	Root Mean Square Error (RMSE)	[22]
$MRDM\% = \frac{100}{N}\sum\frac{\lvert m_i - m_{P_i}\rvert}{m_i}$	Mean Relative DeviationModulus (MRDM MRDM)	[23]
$R^2 = 1 - \frac{Re\ sidual\ SS}{Correected\ total\ SS}$	*Coefficient* Of Determination (R2)	[24]

2-2- Determining the effective penetration coefficient of moisture

Fick's second law is often used to describe the phenomenon of moisture penetration, which is according to equation (4): [25].

$$\frac{\partial c}{\partial \theta} = D_{eff}\frac{\partial^2 c}{\partial z^2}$$

(۴)

$$\frac{\partial c}{\partial \theta} = D_{eff}\frac{\partial^2\ c}{\partial\ z^2}$$

where: cconcentration (Mole/m^3), θ time (s), D_{eff}Effective influence tax (m^2/s) and Z is the spatial specification (m).

Equation (5) was used by solving Fick's equation for the flat and infinite state (red onion slice):[26].

(5)

$$MR = \frac{M_i - M_e}{M_O - M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}[\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_e{}^t}{L^2}\right]\right)$$

where in

D_{It} isEffective coefficient of humidity (m^2/s)

MR : dimensionless humidity ratio

:M_iMoisture content of the product at any time on a dry basis (Kg/Kg)

:M_{It} isEquilibrium humidity at constant temperature on dry basis (Kg/Kg)

:M_0Primary weight on a dry basis (Kg/Kg)

:L*Product thickness*(Due to the low impact of the second terms on the dimension of the series, only the first term is used in the calculations [27].

2-3- Effective penetration coefficient

By taking logarithms from the sides of equation (5), equation number (6) is obtained [28], and the penetration coefficient can be obtained from the slope of this equation according to equation (7) [29].

$$InMR = In\frac{8}{\pi^2} - (-\frac{\pi^2 D_e{}^t}{R_e^2})$$

(۶)

$$Slop = -\frac{\pi^2 D_e}{R_e^2}$$

(۷)

4-2- Activation energy

The relationship between diffusion coefficient and temperature is expressed by the Arrhenius equation (relation (8)). [30] Using equation (8), the activation energy can be obtained [31].

$$D_{eff} = D_0 \exp(-\frac{E_a}{RT})$$

(۸)

where: activation energy and E_a(KJ/mol)

Base diffusion coefficient D_0 (m^2/s)

Gas constant is equal to R 8.314 (J/mol. K)

Absolute temperature (K) T

By taking logarithms by equation (8), this relation can be linearized and by plotting LnD_{eff} Against (1/T) value (E_a/R) is obtained as an angle coefficient, which can be seen in relation (9) [32].

$$Ln_{D_{eff}} = \ln D_0 - (\frac{E_a}{R})(\frac{1}{T})\quad(9)$$

۵-۲- *Anfis*

The parameters of the Takagi-Sugeno inference system were created from the least squares method in the ANFIS model and five layers were created. It includes the fuzzification layer (first layer), the rule layer (second layer), the normalization layer (third layer, the fuzzification layer, the fourth layer). The output layer, (the fifth layer) the input signals are sequentially processed by the above layers and the overall output is obtained from the last layer [33].

In general, taking the ANFIS model with two inputs x and one output f, the fuzzy ifthen rules can be expressed in the following forms.

Rule $_1$: If x is A_1 and y is B_1; then $f_1 = p_1x + q_1 y + r_1$ *(□□)*

Rule $_2$: If x is A_2 and y is B_2; then $f_2 = p_2x + q_2 y + r_2$*(□□)*

where inA_1، A_2، B_1، B_2 *Language tags are and*p_1، p_2، q_1، q_2□ r_1 and r_2 *The output linear coefficients are the function,* f_1 *and* f_2 *are first order polynomials. The first fuzzification layer*

transforms the input variables into a fuzzy set through membership functions where temperature (degrees Celsius), drying time (minutes), f are humidity ratios, converts. *Each node in the first layer is an adaptive node and the corresponding node function is written as*
The first layer (fuzzification) of the input variablesm_{Ai}، $m_{With\ a}$transforms into a fuzzy set through member functions.

$O^1_{Ai}=m_{Ai}(X)$ $_i$=1,2 (۱۲)

$O^1_{Bj}=m_{Bj}$ (AND)$_j$ =1,2(۱۳)
In the second layer (law layer) they are multiplied together and the resulting outputs are expressed in a general form.

$O^2_i In_i m_{Ai}(X)$ $*m_{Ai}$(AND) , …$_{i=1,2}$ (14)
The third layer of normalization using the following equation:

$$Q^3_i = W_i = \frac{W_i}{W1+W2} \quad (15)$$

In the fourth layer, it is generated for the correlation of inputs and outputs in the equation.

$O^4_i=IN_i f_i$ $=W_i$ $(P_{iX}+qiY+ri)=_{i=1,2}$ (۱۶)
The total output is calculated as follows:
In the fifth layer, the output rule summarizes all the inputs and the overall output is as follows:

$$Q^5_i = \sum_i W_i f_i = \frac{\sum_i W_i f_i}{\sum_i W_i} \quad {}_{i=1,2} \qquad (۱۷)$$

*In this research from*A Fuzzy Neural Inference System (ANFIS) was used to predict the moisture content of red onion using the dataset. To evaluate the models,*The temperature of the drying time was considered as the input layer and the humidity ratio as the output. Eight different membership functions, including trapezoidal*trapmf، gbellmf, *curved*Pipimf, *two-way Gaussian*Gasuss2mf, *Difference between two sigmoid functions*dsigmf *And a triangle*trimf, *Gaussian*Gaussmf, *sigmoid function*psigmf *were considered. Meanwhile, the output membership function used was a non-linear function. In addition, from the combined learning algorithm to determine the optimal parameters*Takagi-Sugeno*used. The system infers the predictive ability of the model*ANFIS *Made using the coefficient of determination*R^2, *root mean square error*RMSE, *evaluated*[34]. To perform ANFIS calculations of Neural Network in R software, version 3.6.2. was also used.

3- Results and discussion

Drying curves at different test temperatures are given in Figure (1).

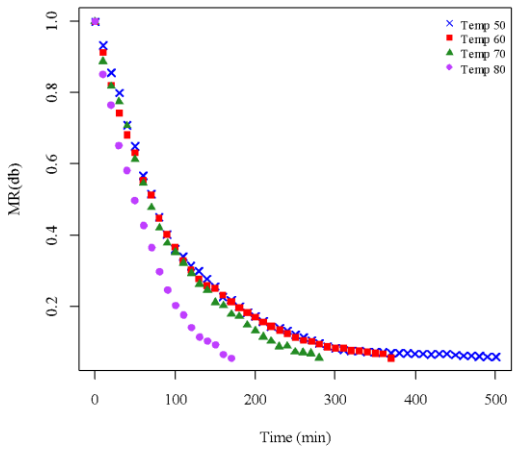

Fig 1 Diagram 1. Red onion drying at different temperatures (50, 60, 70, 80 thC)

As can be seen in Figure (1), at the beginning of the drying process, the initial moisture content of the onion slice and the rate of moisture loss is high, gradually and with the passage of time, the product moisture level decreases and the rate of moisture loss naturally decreases. Finds. Onion loses most of its moisture in the early stages of drying. As a result, it is clear that the slope of the drying curve increases with the increase in temperature, so that the curve has decreased sharply at the temperature of 80 degrees Celsius. The possible reason for this can be the reduction of the pores inside the onion tissue and their shrinking due to shrinkage. As a result of the shrinking of the pores, the partial vapor pressure inside the onion decreases and the resistance to moisture loss increases. Almost for every 10 degrees increase in temperature, the time to reach the final humidity of 20% in terms of dry weight is reduced by 100 minutes. These results withThe result of drying kinetics of carrot thin layers was similar [35]. From the research that was done on the process of changes in after-watering with respect to time, it can be found that onion has lost most of its moisture during the period of descending speed and this period is the most important period of drying of this product. So, the dominant mechanism of moisture transfer during the drying of this product is the water vapor

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diffusion mechanism [36]. By increasing the drying temperature, the potential of evaporation increases and the temperature has a direct effect on the transfer of moisture from the product to the drying air and causes a rapid decrease in the moisture content of red onion and its drying time is reduced. A similar result of this research has been reported regarding the direct effect of temperature on the speed of the thin layer drying process for some vegetables and fruits [37].

The drying intensity of red onion at different temperatures against the amount of moisture is given in figure (2).

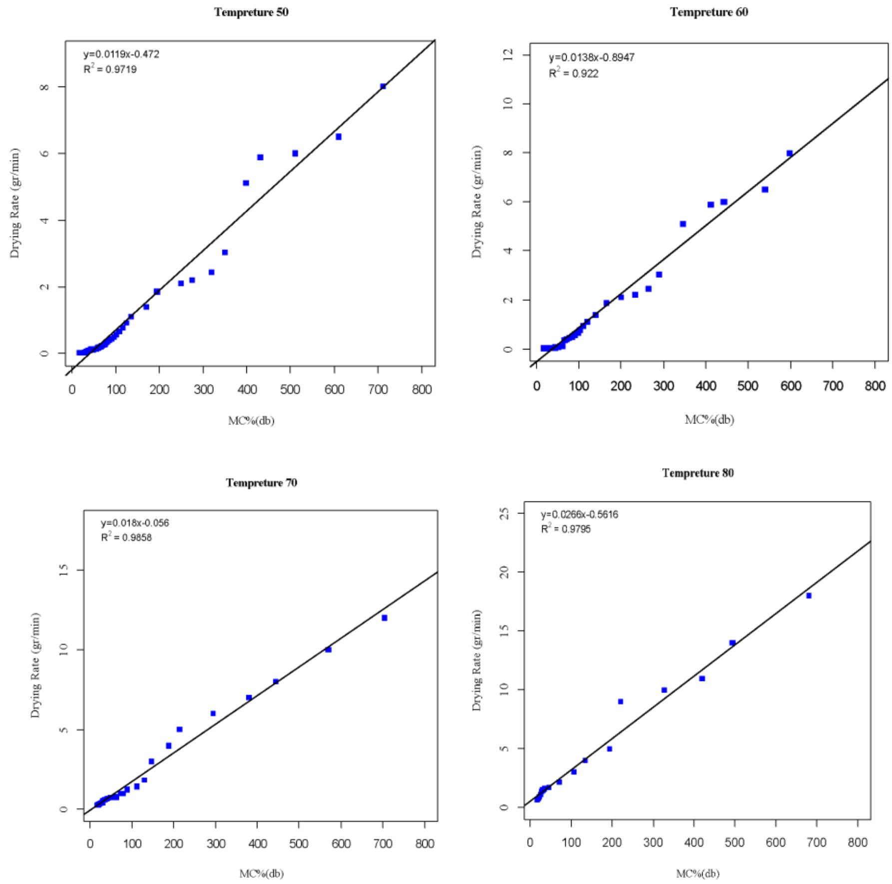

Fig 2 The trend of changes in the drying rate at different temperatures (50, 60, 70, 80 ºC)

The linear regression equation of drying rate was determined in terms of moisture content at different temperatures and is given next to each graph. These linear equations according to the value of R^2They have a good fit. According to these equations, the angle coefficient of the regression line equation increases with increasing temperature and this proves that the drying rate increases with increasing temperature. As can be seen in the figure, the drying of red onion at different temperatures has occurred at a decreasing rate. Also, the drying of the product surface in the final stages of drying creates a resistance in the transfer of water to the product surface, which reduces the intensity of drying in the final stages of drying [30].

The data obtained from red onion drying were fitted with 12 thin layer models according to Table (1). In order to find the best model and obtain their coefficients, the non-linear regression method was used using R version 3.6.2 statistical software using the least squares method. Four indicators were used according to table (2) to measure the best model. The criterion for choosing the best model describing the drying behavior is the highest value of $R^2$and the lowest value of x^2, RMSE and MRDM were. According to the stated contents, among the 12 models, the binomial model had the best match with the test data. The values of the evaluation indices of these two models at different temperatures are given in table (3). Then the coefficients (constants) of the selected models were given to the variables used in the drying process in the correlation table and the results were reported in table (4).

Tables 3 and 4 show the values of constant parameters of the binomial model at different temperatures.

Table 3 Results of model constant parameters for experiments at different temperatures (50, 60, 70, 80 ºC)

R^2	RMSE	X^2	MRDM	T(ºC)	Model
0.998	0.010715	0.000125	3.194168	50	Two term
0.999	0.007364	6.04E-05	2.592504	60	
0.997	0.013003	0.000197	3.326371	70	
0.995	0.01916	0.000437	3.996987	80	

Table 4 Results of nonlinear model fitting of the Two term model in experimental treatments (0.05)

B	A	K_2	K_1	Model Name Two term
1.74e-04	1.00e+00	3.07e-02	1.86e-05	50
9.15e-01	9.37e-02	1.87e-04	3.19e-05	60
1.01e+00	2.06e-09	1.72e-04	8.49e-04	70
9.98e-01	1.93e-07	1.77e-04	8.25e-04	80

The experimental MR values against the predicted MR from the binomial model are given in Figures 3. As it is clear from the graphs, the existing models have a good fit with the experimental data. The evaluation results of the model indices showed that binomial models can better describe the onion drying behavior.

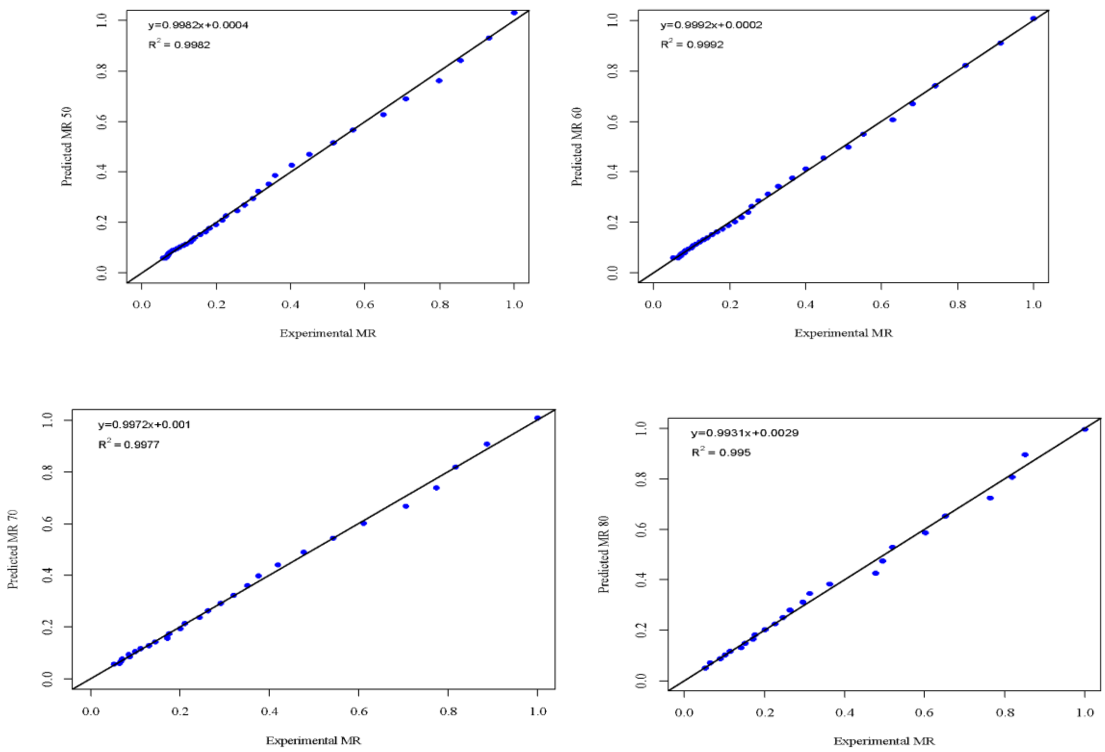

Fig 3 The trend of changes in the drying curve of the Two term model at different temperatures (50, 60, 70, 80 ºC)

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Effective penetration coefficient values at different test temperatures (50, 60, 70,thC 80) is shown in Table 5. Temperature has an effect on the diffusion coefficient and with increasing temperature, the effective diffusion coefficient has an increasing trend.

Table 5 Effective moisture diffusion at different temperatures (50, 60, 70, 80 ºC)

Temperature (ºC)	$D_{eff}\times10^{-10}$(m^2/s)
50	0.01847669
60	0.01930779
70	0.02116988
80	0.03136255

Considering that with the increase in drying temperature, the surface of the product becomes more wrinkled and therefore the side surface of the product is reduced, but this increasing effect of temperature is such that the rate of evaporation of moisture neutralizes the effect of the reduction of the side surface, so with the increase in temperature, the effective penetration coefficient should be increased. . The results of this research are consistent with the reports of other researchers. Effective penetration coefficient values for agricultural products and food in a range$^{۱۱-}$10 to m^2/s$^{۹-}$10 has been reported by researchers [38].

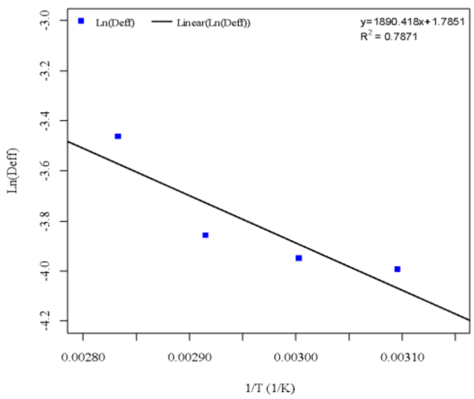

Fig 4 Activation energy determination

Changes in temperature can have a direct effect on the amount of effective diffusion coefficient, and with increasing temperature, the amount of effective diffusion coefficient also increases. The determination of the activation energy is shown in Figure (5) and its value was obtained from the angle coefficient of the regression line of 1890.4 ((kJ/(kg)) [39].

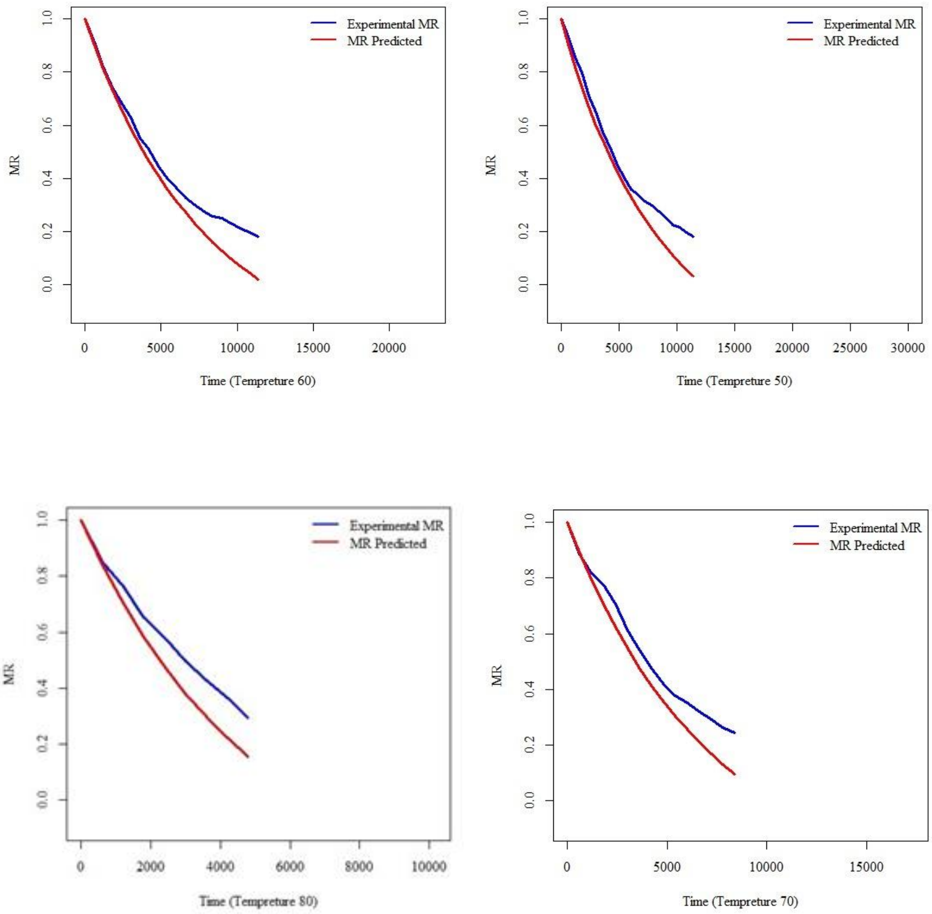

Fig 5 The effect of different temperatures (50, 60, 70, 80 ºC) on the moisture ratio during drying of red onion.

The results of the Fuzzy Neural Inference System (ANFIS) effect of temperature on four levels (50, 60, 70,thC 80) on the moisture ratio during drying of red onion has shown Figure (5). In this research, the results of information related to the best algorithms and for the prediction of Anfis have been reported. It was used in Anfis like other mathematical models. The analysis was carried out on different Anfis models using the trial and error method designed by Endo to predict the output of fuzzy rules, the results of Anfis are summarized in table (7). This table shows that the minimum RMSE and the highest value of R^2 It is provided by the exquisite algorithm.

Table 7 ANFIS results for trimf membership function

R^2	RMSE	Number of functions	Function type
0.999	0.001	2-2-2	trimf
0.999	0.003	2-2-2	gaussmf

4- Comparison of mathematical models and ANFIS

In this research, mathematical models and ANFIS were investigated to predict the moisture ratio of red onion, and the least squared error and MRDM coefficient of determination were used to determine the appropriate model.

By comparing tables (3) and (7), the Anfis model in this research predicts the experimental data better than the mathematical models. The results of similar researches showed that for predicting the drying kinetics of white berry between the mathematical model, artificial neural network and ANFIS [40] and predicting the humidity ratio of pumpkin artificial neural networks according to the value of R^2 Higher and lower RMSE as well as lower error value have better performance for predicting these parameters [41].

5- Conclusion

The behavior of red onion drying in a laboratory dryer at temperatures (50, 60, 70,thC 80) and constant speed (1 m/s) were checked. Drying air temperatures were important factors in calculating the drying time, the amount of effective moisture diffusion coefficient and the activation energy in product drying. Also, twelve mathematical models were used to predict product moisture, and the results showed that the binomial model was the best mathematical model for prediction. Also, the value of effective diffusion coefficient for four temperatures of 50, 60, 70 and 80 ºC respectively (0.01847669, 0.01930770, 0.02116988 and 0.03136255) m^2/s that the effective diffusion coefficient increased with increasing temperature and its changes were in the range of agricultural products and food [30] and [42]. The amount of activation energy of red onion 1890 ((kJ/(kg It was obtained. The amount of activation energy for different food agricultural products is mainly reported between 12.7 and 110 kJ/mol [39]. Based on the data set, several nonlinear and sophisticated prediction models and mathematical models were designed to estimate the moisture ratio of red onion. To design the Enfis model with an output variable of moisture ratio and four input variables, drying time was done. In order to choose the best model for accurate prediction of moisture ratio estimation, the models were compared with each other. In order to choose the best model, the obtained explanation coefficient of the model was calculated and analyzed. According to the experimental data set, the performance prediction of the models and ANFIS binomial model was obtained higher than other models. Therefore, compared to other mathematical models, the ANFIS model had the best result in predicting the moisture ratio of red onion[39].

6- Resources

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تعیین مدل مناسب سینتیک خشک کردن پیاز قرمز و مقایسه مدل‌های ریاضی سیستم استنتاج عصبی فازی (ANFIS)

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چکیده

در این تحقیق، سینتیک خشک کردن، تعیین ضریب نفوذ موثر رطوبت، انرژی فعالسازی و همچنین پیش بینی نسبت رطوبـت پیاز قرمزدر طی فرآیند خشک کردن با خشک کن - هوای داغ به کمک مدل‌های ریاضی و سیستم استنتاج عصبی فازی (ANFIS) انجام گرفت. خشک کردن محصول در چهار سطح دمای ۵۰ ،۶۰، ۷۰ و ۸۰°C در سرعت جریان هوای ثابت m/s ۱ انجام شد. برای انتخاب یک مدل خشک کردن مناسب، دوازده مدل لایه نازک خشک کردن، همچنین استفاده از سیستم استنتاج عصبی فازی (ANFIS) مورد استفاده قرار گرفت. برای تعیین بهترین مدل ریاضی مناسب لایه نازک از رگرسیون غیرخطی و شاخص های R^2 x^2, RMSE, و MRDM در نرم افزار R ویرایش ۳.۶.۲ استفاده گردید. نتایج نشان داد که در میان مدلهای ریاضی مدل دوجمله ای با بیشترین ضریب تبیین و کمترین مقدار ریشه میانگین مربعات خطا مناسب ترین بود. نتایج انفیس با مقدار ضریب همبستگی (R^2 = (۰/۹۹۹ و خطای (۰/۰۰۲)= RMSE کمترین ریشه میانگین مربعات خطا، بهتر از مدل های ریاضی نسبت رطوبت را پیش بینی کرد. مقدار ضریب نفوذ موثر برای چهار دمای ۵۰ ،۶۰، ۷۰و ۸۰°C به ترتیب (۰/۰۱۸٤۷٦٦۹، ۰/۰۱۹۳۰۷۷۰، ۰/۰۲۱۱۶۹۸۸ و ۰/۰۳۱۳٦۲۵۵) m^2/s و مقدار انرژی فعالسازی۱۸۹۰ ((kJ/(kg بدست آمد.