Estimation of Moisture Ratio and Specific Energy Consumption for Apple Slices Drying by Convective and Microwave Methods using Neural Network Modeling

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Abstract: Two different drying methods were applied for dehydration of apple, i.e., convection drying (CD) and microwave drying (MD). The process of convection drying through divergent temperatures; 50, 60 and 70 °C at 1.0 m/s air velocity and three different levels of microwave power (90, 180, and 360 W) were studied. In the analysis of the performance of our approach on moisture ratio of apple slices, artificial neural networks (ANNs) was used to provide with a background for further discussion and evaluation. In order to evaluate the models mentioned in the literature, the Midilli et al. model was proper for dehydrating of apple slices in both MD and CD. The microwave drying technology enhanced the drying rate when compared with convective drying significantly. Effective diffusivity of moisture in CD drying (1.95×10\(^{-7}\) - 4.09×10\(^{-7}\) m\(^2\)/s) was found to be lower than that observed in MD (2.94×10\(^{-7}\)–8.21×10\(^{-7}\) m\(^2\)/s). The Ea values of convective drying and microwave drying were 122.2-125 kJ/mol and 14.01-15.03 W/g respectively. The MD had the lowest SEC as compared to CD drying methods. According to ANN results, the best values for predication of MR in CD and MD were 0.9993 and 0.9990, respectively.

Keywords: Apple; Energy consumption; Drying; Modeling; Artificial neural network;
## Nomenclature

| Symbol   | Description                                                                 |
|----------|-----------------------------------------------------------------------------|
| $MC$     | Moisture content (g water/g dry matter)                                     |
| $W_x$    | Initial weight of sample (g)                                                |
| $W$      | Amount of evaporated moisture (g)                                           |
| $W_y$    | Dry matter content of sample (g)                                            |
| $M_t$    | MC at any time (kg water/kg dry matter)                                     |
| $M_e$    | Equilibrium MC                                                               |
| $M_0$    | Initial MC (kg water/kg dry matter)                                         |
| $R^2$    | Coefficient of determination                                                |
| $RMSE$   | Root mean square error                                                       |
| $\chi^2$| Chi square                                                                   |
| $MR_{exp,i}$ | Experimental value                                                        |
| $MR_{pre,i}$ | Predicted value                                                          |
| $N$      | Number of observations                                                      |
| $Z$      | Constants                                                                    |
| $D_{eff}$| Effective moisture diffusivity (m$^2$/s)                                     |
| $M$      | Material MC (kg water/kg dry matter)                                        |
| $L$      | Half of the slab thickness (m)                                               |
| $i$      | Positive integer                                                            |
| $t$      | Drying time (s)                                                             |
| $E_{a(m)}$| Energy of activation in MD method (W/g)                                      |
| $E_{a(c)}$| Energy of activation in CD method (kJ/mol)                                   |
| $R_g$    | Universal gas constant (8.3143 kJ/mol)                                      |
| $T_a$    | Absolute air temperature (K)                                                |
| $U_n$    | Normalized value                                                            |
| $U_R$    | Actual value                                                                 |
| $U_{max}$| Maximum of the actual value                                                  |
| $U_{min}$| Minimum of the actual value                                                  |
| $D_0$    | Constant number                                                             |
| $P$      | Output power of microwave (W)                                               |
| $E_u$    | Energy of activation in MD method (W/g)                                      |
| $m$      | Weight of raw sample (g)                                                    |
| $W_{sec}$| Specific energy consumption in MD method                                    |
| $W_{mic}$| Specific energy consumption in CD method                                     |
| $Q$      | Inlet air to drying chamber (m$^3$/min)                                     |
| $t_1$    | Drying time (s)                                                             |
| $t_2$    | Total drying time (min)                                                     |
| $h_v$    | Absolute air humidity (kg vapor/kg dry air)                                 |
| $T_{in}$ | Inlet air to drying chamber temperature (°C)                                 |
| $T_{am}$ | Ambient air temperature (°C)                                                |
| $m_w$    | Mass of evaporated water (kg)                                               |
| $\Delta h$| Lightness difference                                                        |
| $\Delta a$| Intensity of the color red                                                  |
| $\Delta b$| Intensity of the color yellow                                               |
1. Introduction

Apple (Malus domestica Borkh.) is one of the oldest fruits known to mankind and has grown to
nourish it. It is one of the most important horticultural products in the world, and countries such as
China, the United States, Turkey, Poland, India, the Russian Federation and Iran are considered as
major apple producers. Apples, like many other fruits, have a high water content (80–85% on w.b.).
Apple is rich in vitamins, minerals and fiber and is usually consumed raw, but it is used in many foods
(especially desserts) and beverages. Drying, in addition to being a way to increase the shelf life of
foods, is known as a way to increase the value added of food products. Removing water from a
product under controlled conditions reduces the moisture content of the food to a certain extent, which
lessens the activity of enzymes, the rate of undesirable chemical changes and microbial growth. Also,
the decrease in moisture is accompanied by a reduction in volume and weight, which is one of the
important factors for transportation and maintenance. Throughout the decades, hot air drying method
has been one of the most long-established technologies in the food industries. The process of hot air
drying includes both the heat and mass transfer while the water is provided by the agricultural
products through diffusion. However the total energy of this diffusion goes hand in hand with air
temperature, time and air velocity. One of the methods that has been given a lot of attention during
the last decade is drying using microwave radiation. Microwave beams are electromagnetic beams
with a long wavelength of 2450 MHz. During the passing of these waves from the tissue of matter,
polar molecules, such as water and salts, vibrate, and this vibration causes the microwave energy to be
converted into heat. Unlike other methods of drying, in which heat should penetrate from the surface
to depth, in this method heat is produced in the tissue of the food itself and it is prevented from
damaging the superficial parts of the food. Different methods are used to reduce the moisture content
of fruits and vegetables. Izli and Isik used microwave, convective, and microwave-convective dryers
to dry tomatoes. They showed that microwave-convective dryers require less time to dry tomatoes.
Seremet et al. investigated effect of different drying methods (Hot air convection and hot air
convection-microwave dryer) on weight loss and rehydration of sliced pumpkin. Drying of sorbus
fruits by convective (50°C and 70°C at air velocity of 0.3 m/s) and microwave (90, 160 and 350 W)
were studied in order to determine the drying behaviors. The results showed that the temperature of 50
°C and the microwave power of 90 W had the slightest variations in color. Also, the lowest specific
energy consumption were 0.69 kWh/kg and 37.07 kWh/kg respectively at 70°C and 350 W. The
correlation of the unpredictable input and output process parameters interconnection follows the
stimulated computing approach named Artificial Neural Network (ANN). ANNs are capable of
modeling nonlinear and complex systems with a large number of input and output data. The ability to
predict a neural network is completely dependent on its structure (type of activation function, number
of layers and number of hidden layer neurons). In recent years, methods based on ANNs have been
used to predict the moisture content of many food and agriculture products during the drying process, including green peas, tomatoes, corn and pomegranate seeds\textsuperscript{14-17}. In this research, the neural network modeling method was used to estimate the moisture ratio of apple slices during drying in microwave and hot air dryer. The results of this model are compared with the results of mathematical modeling to determine its effectiveness. Also, moisture diffusion coefficient, activation energy, specific energy consumption and color changes were also determined for apple slices.

2. Material and methods

2.1. Sample preparation

Apple was supplied from one of apple orchards of Ardabil city, Iran, in September 2016. Generally, apple samples of uniform sizes were selected. The apple fruit were cleaned and stored in a refrigerator at 4±1°C. The premature and spoiled apple was separated manually. The initial MC of apple slices was measured by oven drying method. Apple slices to the nearest 40 g (4 mm thickness and 36 mm diameter) in triplicate samples were dehydrated at 70±1°C for 24 h\textsuperscript{18}. Apple fruit with average initial MC of 45% (d.b.) was selected for drying material.

2.2. Experimental procedure

2.2.1. Convective dryer

Convective drying (CD) was conducted by using laboratory drying oven (BF55E; FG Co., Iran). The velocity of the air approaching to the apple samples was measured by an anemometer (Lutron AM-4202; Electronic Enterprise Co., Taipei, Taiwan) with ±0.1 m/s accuracy and the average air velocity was 1.2 ± 0.02 m/s. Electrical heating unit of this dryer equipped with PT100 thermometer sensor and PID controller with ±0.1C accuracy. Average humidity and air temperature of ambient air during convection dryer were 30% and 26°C, respectively.

2.2.2. Microwave dryer

A fully programmable microwave oven (Panasonic NN-CD997S Microwave Oven) with maximum output of 1000 W was utilized for this study. The microwave oven has the capability of operating at different microwave output powers, 90, 180, 270, 360, 450, 540, 630, 720, 900 and 1000 W. The microwave drying area is 462 mm, 242 mm and 412 mm inner size and includes a 380 mm diameter rotary glass plate at the oven base. The microwave output power and processing time was set fully by using digital control panel of microwave oven.

2.3. Experimental setup

2.3.1. Determination of moisture ratio
Drying curves may be represented in different ways; MC (wet and dry base) versus time, drying rate versus time, or drying rate versus MC. The MC of apple was calculated by using Equation 1:

\[ MC = \frac{((W_s - W) - W_{y})}{W_y} \]  

(1)

\[ MR = \frac{(M_t - M_e)}{(M_0 - M_e)} \]  

(2)

It should be noted that due to the insignificant value of \( M_e \) in comparison with \( M_t \) and \( M_0 \), it can be saved. Therefore Equation 2 can be simplified to Equation 3:

\[ MR = \frac{M_t}{M_0} \]  

(3)

### 2.3.2. Mathematical modelling of drying curves

The models listed in Table 1 were used for mathematical modeling drying kinetics of apple slice in MD and CD. To compare the data to each model, curve expert was used for curve fitting. This software has linear and nonlinear regression models and various interpolation methods. In order to select the suitable drying kinetics descriptor, the statistical parameters of \( R^2 \), \( RMSE \) and \( \chi^2 \) were used. Finally, the drying model with maximum \( R^2 \) and minimum \( RMSE \) and \( \chi^2 \) was selected as the appropriate model for describing drying kinetics. The mentioned statistical parameters are defined by the following equations:

\[ R^2 = 1 - \frac{\sum_{i=1}^{N} [MR_{exp,i} - MR_{pre,i}]^2}{\left( \sum_{k=0}^{n} \frac{\sum_{i=1}^{N} MR_{pre,i}}{N} - MR_{pre,i} \right)^2} \]  

(4)

\[ \chi^2 = \frac{\sum_{i=1}^{N} (MR_{exp,i} - MR_{pre,i})^2}{N - z} \]  

(5)

\[ RMSE = \left[ \frac{1}{N} \sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2} \]  

(6)

Exponential equation form of Equation 2 can be used as follows:

\[ MR = \frac{M_t - M_e}{M_0 - M_e} = \exp(-kt^n) \]  

(7)
Table 1. Mathematical empirical drying models given by various authors for the drying curves

| Models        | Equation                        | References |
|---------------|---------------------------------|------------|
| Midilli et al.| \( MR = a\exp(-kt^n) + bt \)   | 25         |
| Page          | \( MR = \exp(-kt^s) \)         | 26         |
| Logistic      | \( MR = a/(1 + b\exp(kt)) \)   | 27         |
| Two-term      | \( MR = a\exp(-k_1t) + b\exp(-k_2t) \) | 28 |
| Logarithmic   | \( MR = a\exp(-kt) + c \)     | 29         |

2.3.3. Effective moisture diffusivity

Mass transfer during food drying is a complex process involving various mechanisms such as molecular penetration, movement in capillary tubes, and liquid penetration in the porous materials, penetration of vapor in air pores and hydrodynamic flow, or surface propagation. Moisture penetration is one of the most important factors controlling the drying process. When different mechanisms are effective in transmitting, it is difficult to examine each mechanism and measure the mass transfer rate in each one. Hence, in such processes, the description of effective diffusion is used and its concept is described by the Fik’s second law as follows:\(^30\):

\[
\frac{\partial M}{\partial t} = D_{eff} \nabla^2 M
\]  
(8)

Calculation of effective diffusion coefficient using the Fik’s second law is a tool for describing the drying process and possible mechanisms for the transfer of moisture within food products. The analytical solution of Fik’s law is as follows:\(^31\):

\[
MR = \frac{M_i - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2i + 1)^2} \exp\left(-\frac{(2i + 1)^2 \pi^2}{4L^2} D_{eff} t\right)
\]  
(9)

Where \( i \) is a positive integer that is equal to 1 for long drying time. Therefore, Equation 9 can be written in simpler form as Equation 10:

\[
MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right)
\]  
(10)

The coefficient \( K_1 \) is calculated by plotting the curve \( \ln(MR) \) versus time, in accordance with Equation 11 as follows:\(^32\):

\[
K_1 = \left(\frac{D_{eff} \pi^2}{4L^2}\right)
\]  
(11)
2.3.4. Activation energy

Dependence of the diffusion coefficient with temperature is shown using the Arrhenius equation (Equation 12). Activation energy of the convective dryer \( E_{a(c)} \) was determined by plotting the effective moisture diffusion coefficient curve versus absolute air temperature reversal.  

\[
D_{\text{eff}} = D_0 \exp\left(\frac{E_{a(c)}}{R_g T_a}\right)
\]  

Equation 12

The linear form of Equation 12 can be obtained by applying the logarithms as:

\[
\ln(D_{\text{eff}}) = \ln(D_0) - \left(\frac{E_{a(c)}}{R_g T_a}\right)
\]  

Equation 13

\( K_2 \) can be obtained by plotting \( \ln(D_{\text{eff}}) \) versus \( \frac{1}{T_a} \):

\[
K_2 = \frac{E_{a(c)}}{R_g}
\]  

Equation 14

Linear regression analyses were used to fit the equation to the experimental data to obtain correlation coefficient \( R^2 \).

The activation energy for microwave dryer \( E_{a(m)} \) was calculated by using a correlation between effective moisture diffusivity and \( \frac{m}{P} \) is taken into account:

\[
D_{\text{eff}} = D_0 \exp\left(-\frac{E_{a(m)} m}{P}\right)
\]  

Equation 15

\( E_{a(m)} \) may be accomplished using one of several methods as follows:

\[
\ln(D_{\text{eff}}) = \ln(D_0) - \left(\frac{E_{a(m)}}{P} m\right)
\]  

Equation 16

Following plotting of \( \ln(D_{\text{eff}}) \) versus \( 1/P \), \( K_3 \) is calculated for the microwave as follows:

\[
K_3 = \frac{E_{a(m)}}{P}
\]  

Equation 17

2.3.5. Specific energy consumption

The specific energy consumed during the drying process, which is the amount of energy used to evaporate one kilogram of water from the product, was obtained using Equation 18 under microwave drying method:

\[
SEC_{\text{mic}} = 60 \frac{P_{\text{mic}} t_{1}}{m_w}
\]  

Equation 18
Specific energy consumption \((SEC_{con})\) of apple slice in CD approach was measured through the Equation 19 as follows\(^{36,37}\):

\[
SEC_{con} = (C_{pa} + C_{pe}h_a)Q_t \left(\frac{T_{in} - T_{am}}{m_rV_h}\right)
\]  

(19)

2.3.6. Color

Three color schemes, including RGB, CMYK and Lab, are used to determine the color of food. The Lab model is often used for food color research studies. L demonstrates brightness in the range 0-100, and two colored components (-120 - +120) including a (greenness to redness) and b (blueness to yellowness). The color parameters of apple slice were measured using digital portable colorimeter (CR-10-PLUS, Konica Minolta Co, Japan), appropriate test method based on CIELAB. Total color changes \((\Delta E)\) was calculated using Equation 20. All color changes were obtained with averaging in six replicates samples\(^{38,39}\):

\[
\Delta E = \left[ (\Delta L)^2 + (\Delta b)^2 + (\Delta a)^2 \right]^{0.5}
\]  

(20)

2.3.7. ANN

ANN was used for modeling the drying process of apple slice in microwave and hot air dryer to predict MR by using Matlab software. In this research, the Levenberg-Marquard optimization method was used to learn the network. The inputs for ANN model are drying time, and drying chamber inlet air temperature, and the output is MC variations of apple slice. Figure 1 shows ANN inputs and output structure with two hidden layers.

![Four-layer ANN inputs and output structure used in this study](image)

2.3.7.1. Convective dryer

Apple slice drying experiments were done at 50, 60 and 70°C set temperature. The two input parameters had applied in the experiments with convective dryer. The moisture ratio (MR) values were derived. Networks with two neurons in the input layer (air temperature and drying time) and one
neuron in the output layer (MR) were designed. In this part, the total data of, moisture ratio (163 data) for artificial neural networks were used. In the first group, 70% (115 data) were taken for training phase and in the second group 30% (48 data) for testing, chosen randomly from the set of 163 data.

2.3.7.2. Microwave dryer

Applying the two inputs in all experiments, the moisture ratio values obtained for different conditions. Networks with two neurons in input layer (microwave power and drying time) and one neuron in output layer (MR) were designed. About 70% (49 data) of the all experimental data (70 data) were separated for network training to find suitable structure.

Prior to training the neural network, input data normalized to it. The purpose of normalizing is to convert data between zero and one. Therefore, the following equation was used for normalization:

\[
U_n = \frac{U_R - U_{\text{min}}}{U_{\text{max}} - U_{\text{min}}}
\]  

In order to evaluate the accuracy and performance of the developed models of artificial neural networks, the statistical criteria of the coefficient of determination (R^2), root mean square error (RMSE) and mean absolute error (MAE) were used. The mentioned statistical parameters calculated using the following equations:

\[
MSE = \frac{1}{mq} \sum_{p=1}^{m} \sum_{i=1}^{q} (S_{yi} - T_{yi})^2
\]  

\[
R^2 = 1 - \frac{\sum_{i=1}^{n} [S_i - T_i]}{\sum_{i=1}^{n} S_i - \frac{\sum_{i=1}^{n} S_i}{n}}
\]  

\[
MAE = \frac{100}{n} \sum_{i=1}^{n} \left| \frac{S_i - T_i}{T_i} \right|
\]

3. Results and discussion

3.1. Drying characteristics (Convective and microwave drying kinetics)

Changes in moisture ratio of apple slice with drying time at different air temperatures 50, 60, and 70°C and air velocity 1 m/s were presented in Figure 2a. The drying experiments of apple slices continued until the moisture content of the samples reached about 0.18 (d.b.) in both drying methods. As can be seen in Figure 2a, increase of air temperature from 50 to 70 °C causes a decrease on final product drying time, which is consistent with the results of Beigi\textsuperscript{42} and Kaleta et al.\textsuperscript{43}. In the process of convective drying, increasing air temperature from 50 to 70 °C resulted to increase in mass transfer, reduce process time and energy consumption\textsuperscript{44}. Drying time for apple slice in air velocity 1 m/s, were 200, 150 and 100 min at 50, 60 and 70°C, respectively. Kara and Doymaz\textsuperscript{44} reported that the drying times of apple pomace at air velocity 1 m/s for four air temperatures 50, 60, 70 and 80°C. An
increment in air temperature caused also a decrease in drying time at apple pomace. Beigi reported that air temperature had a shorter effect on drying time in Hot air drying of apple slices at 1.5 m/s air velocity 50, 60 and 70°C. Effect of air temperature (50, 65, 80 and 90°C), three levels of drying product thickness (3.5, and 7 mm), engine load levels (25, 50, 75, and 100%), and air velocity (1 m/s) on moisture ratio of apple slices in combined heat and power (CHP) dryer have been investigated by Samadi et al. With increasing of air temperature in the tested range, the amount of moisture removed from apple slices increased.

Changes in MR of apple slice with drying time in microwave dryer at different microwave power (90, 180 and 360 W) were shown in Figure 2b. As shown in Figure 2b, it can be seen that the rate of water loss in MD method was higher than CD, due to the electromagnetic heating effect of microwave in drying food products. Also, with higher microwave power, more heat generated within the sample created a larger vapor pressure difference between the center and the product surface. Thus accelerated the interior moisture migration and increased surface water evaporation.

The times of the drying process in MD were 50, 80 and 130 min at 360, 180 and 90 W, respectively. The results showed that with increasing microwave power, the drying time had a downward trend. Similar results were obtained for drying crops in a microwave dryer such as pomegranate arils, mushroom, tomatoes and broccoli stalk slice.

In order to mathematical modeling of apple slice drying kinetics in the convective dryer, five commonly mathematical models for thin layer products were used (Table 1). For all convective drying experiments (50, 60 and 70°C air temperature and 1 air velocity), determination coefficient ($R^2$), root mean square error (RMSE), and reduced Chi square ($\chi^2$) values ranged between 0.9932–0.9999, 0.0172–0.0845 and 0.0003–0.0468, respectively. From Table 2, Midilli et al. model had the highest $R^2$ (0.9994–0.9999) and the lowest RMSE (0.0194–0.0274) and $\chi^2$ (0.0004–0.0041) values. Therefore, the Midilli et al. drying model was achieved as appropriate one for describing drying behaviors of apple slices. Chayjan et al. tested five empirical models (Midilli et al., Demir et al.,
Logistics, Logarithmic and Wang and Singh) in their research for continuous band drying of eggplant slices and claimed that all models described well drying kinetics at studied air temperatures, air velocities and infrared power. Midili et al. model was chosen as the best model for describing the moisture ratio of the sour cherry. Torki-Harchegani et al.\textsuperscript{51} examined the kinetics of drying lemon slices in convective dryer at 50, 60 and 75°C air temperature. Their results showed that the drying temperature had a significant effect on the drying time and drying rate. Among the models used, the Midilli et al. model was proposed as the best model for prediction moisture content of lemon slices.

### Table 2. The statistical comparison for prediction drying of apple slices in convective dryer

| Model          | \( R^2 \)   | \( \chi^2 \)   | RMSE   |
|----------------|------------|--------------|--------|
|                | 50 °C | 60 °C | 70 °C | 50 °C | 60 °C | 70 °C | 50 °C | 60 °C | 70 °C |
| Midili et al.  | 0.9999 | 0.9998 | 0.9998 | 0.0003 | 0.0009 | 0.0010 | 0.0172 | 0.0211 | 0.0221 |
| Page           | 0.9998 | 0.9998 | 0.9996 | 0.0007 | 0.0011 | 0.0014 | 0.0282 | 0.0681 | 0.0741 |
| Logistics      | 0.9993 | 0.9991 | 0.9989 | 0.0039 | 0.0059 | 0.0103 | 0.0268 | 0.0302 | 0.0398 |
| Two-term       | 0.9966 | 0.9941 | 0.9932 | 0.0222 | 0.0401 | 0.0468 | 0.0629 | 0.0886 | 0.0845 |
| Logarithmic    | 0.9998 | 0.9994 | 0.9990 | 0.0018 | 0.0028 | 0.0031 | 0.0224 | 0.0240 | 0.0251 |

The results of the fitting of apple slices drying data in microwave method with different mathematical models were presented in Table 3. For all microwave drying experiments, \( R^2 \), RMSE and \( \chi^2 \) values ranged between 0.9966–0.9999; 0.0188–0.0421 and 0.0005–0.0291. Midili et al. model had the highest \( R^2 \) (0.9999) and the lowest RMSE (0.0188) and \( \chi^2 \) (0.0005) values. Therefore, Midili et al. model was proposed as the best model for drying apple slice in MD. Darvishi et al.\textsuperscript{52} dried white mulberry in microwave drying at 100, 200, 300, 400 and 500 W power levels and applied the experimental data to five thin layer models where Lewis, Henderson and Pabis, Page, Wang and Singh, and Midilli et al. models tested. Diffusion model gave the best results (maximum values \( R^2 = 0.99958 \), minimum values RMSE (0.00429) and \( \chi^2 \) (0.00019)).

### Table 3. The statistical comparison for prediction drying of apple slices in microwave dryer

| Model          | \( R^2 \)   | \( \chi^2 \)   | RMSE   |
|----------------|------------|--------------|--------|
|                | 90 W | 180 W | 360 W | 90 W | 180 W | 360 W | 90 W | 180 W | 360 W |
| Midili et al.  | 0.9999 | 0.9996 | 0.9994 | 0.0005 | 0.0021 | 0.0027 | 0.0188 | 0.0249 | 0.0251 |
| Page           | 0.9994 | 0.9991 | 0.9995 | 0.0057 | 0.0084 | 0.0148 | 0.0279 | 0.0313 | 0.0410 |
| Logistics      | 0.9981 | 0.9967 | 0.9967 | 0.0077 | 0.0194 | 0.0272 | 0.0304 | 0.0501 | 0.0596 |
| Two-term       | 0.9976 | 0.9974 | 0.9968 | 0.0116 | 0.0243 | 0.0324 | 0.0359 | 0.0564 | 0.0618 |
| Logarithmic    | 0.9968 | 0.9979 | 0.9966 | 0.0018 | 0.0051 | 0.0291 | 0.0231 | 0.0268 | 0.0421 |
3.2. Effective moisture diffusivity

Effective moisture diffusivity values ($D_{eff}$) of apple slice at different dryer calculated by Equation (10). The Reported $D_{eff}$ values were within the general range of $10^{-8}$ to $10^{-12}$ m$^2$/s for agricultural product and food materials. In convective drying, minimum $D_{eff}$ value ($1.95 \times 10^{-7}$ m$^2$/s) belonged to pretreated apple slice of at air temperature 40°C, and maximum value ($4.09 \times 10^{-7}$ m$^2$/s) belonged to apple slice at air temperature 70°C. Obtained values were demonstrated in Figure 3a. The results indicated direct correlation between $D_{eff}$ and temperature. Increasing the air temperature was accompanied by an increase in $D_{eff}$ and a reduction in the drying time. Beigi estimated as $7.03 \times 10^{-10}$ to $1.08 \times 10^{-9}$ m$^2$/s for apple in convective dryer at 50°C and 70°C, 1.5 m/s air velocity. The values of $D_{eff}$ are comparable with the reported values of $1.73 \times 10^{-10}$ to $4.40 \times 10^{-10}$ m$^2$/s for apple pomace at 50 to 80°C and air velocity of 2 ± 0.1 m/s in convective dryer, 6.97 $\times 10^{-11}$ to 2.38 $\times 10^{-10}$ m$^2$/s for quince slices drying in convective dryer and $3.27 \times 10^{-9}$ to $1.23 \times 10^{-8}$ m$^2$/s consideration for broccoli slices with air temperatures of 45–70°C and air velocities of 2 m/s in convective dryer.

The values of $D_{eff}$ for microwave dryer are presented in Figure 3b. In microwave drying, minimum value ($2.94 \times 10^{-7}$ m$^2$/s) belonged to apple slice which had a microwave power level of 90 W; maximum value ($8.21 \times 10^{-7}$ m$^2$/s) belonged to apple slice that had a microwave power level of 360 W. According to the results the values of $D_{eff}$ in MD were higher than CD. Also, the microwave power and lower air velocity can accelerate the water molecules present in the apple slice to evaporate faster, thus providing a faster decrease of the apple slice MC and the corresponding higher value of effective moisture diffusivity.

![Graphs](image-url)

**Figure 3.** Effective moisture diffusivity ($D_{eff}$) for drying of apple slice in different:

a) air temperature, b) microwave power

Similar results for the amount of $D_{eff}$ in microwave dryers are provided by other authors for fruits and vegetables. For example: effective moisture diffusivity values for ginger rhizomes was obtained
ranged from $20.24\times10^{-12}$ to $9.8\times10^{-11}$ m$^2$/s at 100 – 900 W$^{53}$. $D_{ef}$ values for bamboo shoot slices increased from $4.15\times10^{-10}$ to $22.83\times10^{-10}$ m$^2$/s at different power levels ranging from 140 to 350 W in microwave dryer$^{56}$ and effective diffusivity of mulberry increased with increasing microwave power. It varied from $1.06\times10^{-8}$ to $3.45\times10^{-8}$ m$^2$/s at five microwave powers of 100, 200, 300, 400 and 500 W$^{57}$.

3.3. Activation energy

During the drying process, the highest values of activation energy for CD and MD methods were obtained 125 kJ/mol and 15.03 W/g, respectively (Table 4). The air temperature and microwave power were important factors influencing the effective moisture diffusivity and activation energy. By increasing the temperature and microwave power, the activation energy was reduced as the result of mass transfer and more moisture loss of apple slice. The obtained results are in line with the stated values for hot air drying of cherry tomato (31.99 and 36.21 kJ/mol for the raw and blanched cherry tomatoes$^5$, and microwave drying of kiwi slices (17.96–21.38 W/g)$^{57}$.

3.4. Specific energy consumption (convection and microwave)

Table 4. The estimated activation energy in convective and microwave dryer

| Air temperature (°C) | 50  | 60  | 70  |
|----------------------|-----|-----|-----|
| Ea (kJ/mol)          | 125 | 124.44 | 122.28 |
| Microwave power (W)  | 90  | 180 | 360 |
| Ea (W/g)             | 15.03 | 14.50 | 14.01 |

As shown in Figure 4a, during the drying process of apple slices in microwave dryer, the specific energy consumption at 90 and 360 W microwave power were obtained 80.05 and 52.03 (MJ/kg), respectively. In other words, the ratio of highest to lowest value of specific energy consumption was 1.53. According to the results, with the increase in microwave power, the specific energy consumption dropped significantly. The reduction in specific energy consumption at higher microwave power in MD method is due to the effect of its volumetric heating, which reduces the drying time$^{37}$. Advantages such as shorter drying times and lower energy consumption were the key drivers for the further
development of the microwave drying technique. The minimum value of SEC for drying of sunflower seeds were obtained to be 5.81 MJ/kg at microwave power 300 W and the maximum and minimum values of energy consumption in microwave drying for tomato were obtained to be 350 and 8.4 Wh, respectively at range 90–600 W.

![Figure 4. Variations of specific energy consumption for drying process of apple slice in different: a) air temperature, b) microwave power](image)

### 3.5. Color for (convection and microwave)

Color is one of the most important qualitative properties of fresh, processed food and its marketing. As shown in Figure 5a, color variations (ΔE) at different temperatures of 50, 60 and 70°C are shown in convective dryer. The most and the least amount of color variations (ΔE) occurred at temperatures of 70 and 50°C, respectively. According to the results, with the increase in air temperature of the dryer, the amount of color changes (ΔE) increased due to the decrease in moisture content in apple slice and the shrinkage process. During the drying process, oxidation occurs and as a result of this oxidation, the intensity of the color decreases. The color change (ΔE) of pomegranates arils (6.80–14.16 N) at hot air dryer were reported by Horuz and Maskan. The minimum color change (9.316) was obtained at air velocity of 2 m/s, air temperature (60°C) and belt linear speed of 2.5 mm/s, while the maximum color change was 18.24 MJ/kg observed at 1.5 m/s air velocity, air temperature 40°C and belt linear speed (mm/s) of 10.5 mm/s, for terebinth.

As shown in Figure 5b, color changes in microwave dryer increased by increasing microwave power from 90 to 180 W. The microwave power and process time are the effective factors influencing the color change in the microwave dryer. Due to the heat, the chlorophyll green pigments may turn into pheophytin, which has a brownish color. The change in the color of the pigments can be due to the effect of heat on heat-sensitive compounds such as carbohydrates, proteins and vitamins, which also causes color change during the drying process.
Figure 5. Color change values of apple slices in different a) air temperature, b) microwave power

3.6. ANN

3.6.1. Convective dryer

Table 5 presents the best results for combining CFBF and FFBF networks with different topologies and activation functions to predict the moisture ratio of apple slices in CD method. According to Table 5, we can get the best performance of the FFBF network, which with the topology 2-10-10-1, along with the TAN, TAN and PUR threshold function and LMA (Levenberg-Marquardt algorithm) for training neural network, has the best result through the three-layer and four-layer topologies. The selected topology created the highest level of correlation (0.9993 for train and 0.9994 for test) and the lowest values of MAE and MSE achieved were 0.0047 for train, 0.0041 for test and 0.00044 respectively, for output variables. Tavakolipour et al.63, the moisture ratio of zucchini were predicted by using artificial neural networks at convective dryer. According to the results, the coefficient of determination 0.998 and the RMSE value (0.0335) for the moisture ratio was obtained.

Table 5. The best values of evaluation criteria for FFBF and CFBF networks in different conditions of the number of layers and threshold functions for MR in convective dryer

| Network | Training algorithm | Threshold function | Number of layers and neurons | MSE Train | MAE Train | R^2 Train | MSE Test | MAE Test | R^2 Test |
|---------|------------------|-------------------|----------------------------|----------|-----------|-----------|----------|----------|----------|
| FFBP    | LM               | TAN-TAN-PUR       | 2-10-10-1                  | 0.00044  | 0.9993    | 0.9994    | 0.0041   | 0.9993   | 0.0041   |
| FFBP    | BR               | TAN-LOG-PUR       | 2-15-10-1                  | 0.00099  | 0.9988    | 0.9909    | 0.0076   | 0.9909   | 0.0076   |
| CFBP    | LM               | TAN-TAN-PUR       | 2-12-1                     | 0.00084  | 0.9991    | 0.9992    | 0.0057   | 0.9992   | 0.0057   |
| CFBP    | BR               | TAN-TAN-TAN       | 2-8-8-1                    | 0.00102  | 0.9988    | 0.9989    | 0.0082   | 0.9989   | 0.0082   |

3.6.2. Microwave dryer

Table 6 presents the best networks with the highest R^2 values and the lowest MAE and MSE values for prediction MR of apple slices in microwave dryer. The cascade forward back propagation (CFBP) structure, TAN- TAN- TAN threshold function, LM algorithm with 2-15-10-1 topology structure had
the lowest $MSE$ (0.00059), $MAE$ (0.0045 for test and 0.0053 for train) values and the highest $R^2$ (0.9993 for test and 0.9991 train) values (Table 6).

Table 6. The best values of evaluation criteria for FFBF and CFBF networks in different conditions of the number of layers and threshold functions for MR in microwave dryer

| Network | Training algorithm | Threshold function | Number of layers and neurons | $MSE$ | Train $R^2$ | Test $R^2$ | Train $MAE$ | Test $MAE$ |
|---------|--------------------|--------------------|------------------------------|-------|-------------|------------|-------------|------------|
| FFBP    | LM                 | TAN-PUR-LOG        | 2-5-5-1                      | 0.00080 | 0.9988      | 0.9989     | 0.0070      |            |
| FFBP    | BR                 | TAN-LOG-TAN        | 2-10-1                       | 0.00064 | 0.9990      | 0.9990     | 0.0059      | 0.9992     |
| CFBP    | LM                 | TAN-TAN-TAN        | 2-15-10-1                    | **0.00059** | **0.9991** | **0.9993** | **0.0045** |            |
| CFBP    | BR                 | TAN-TAN-PUR        | 2-8-8-1                      | 0.00095 | 0.9984      | 0.9986     | 0.0088      |            |

4. Conclusion

The effects of CD and MD at different air temperatures (50, 60 and 70°C), and microwave powers (90, 180, and 360 W) on the drying characteristics of apple slice were evaluated in this study. The drying time of apple slice was the highest in MD drying as compared to another one. Midili et al. model was the most suitable model for prediction of apple MR. This model had the highest correlation coefficients ($R^2$) and lowest chi-square ($\chi^2$) and root mean square error ($RMSE$) values. So, it can be able to describe the thin layer drying characteristics of samples at two dryers. The maximum $D_{eff}$ value of $8.21\times10^{-7}$ m²/s was obtained under the MD with power of 360 W. The minimum SEC value (52.03 MJ/kg) was obtained from microwave drying. The obtained $R^2$ values using ANN for predication of MR at two different dryers (data test) were equal to 0.9993 and 0.9990 in CD and MD, respectively.

5. References

1. Aghbashlo, M., Kianmehr, M. H., & Arabhosseini, A. Modeling of thin-layer drying of apple slices in a semi-industrial continuous band dryer. *Int. J. Food Eng.*, 6(4), 1-6 (2010).
2. Antal, T., & Kerekes, B. Investigation of Hot air-and infrared-assisted freeze-drying of apple. *J. Food Process. Preserv.*, 40(2), 257-269 (2016).
3. Shalini, R., & Gupta, D. Utilization of pomace from apple processing industries: a review. *J. Food Sci. Technol.*, 47(4), 365-371 (2010).
4. Adam, K. L. Food Dehydration Options. US: National Sustainable Agriculture Information Service. Aeroglide Corporation, Cary, NC. 919-851-2000 (2004).
5. Cheng, L.-S., Fang, S., & Ruan, M.-L. Influence of blanching pretreatment on the drying characteristics of cherry tomato and mathematical modeling. *Int. J. Food Eng.*, 11(2), 265-274 (2015).
6. Funebo, T., Ahné, L. I. a., Kidman, S., Langton, M., & Skjöldebrand, C. Microwave heat treatment of apple before air dehydration–effects on physical properties and microstructure. *J. Food Eng.*, 46(3), 173-182 (2000).
7. Prothon, F., Ahrné, L. I. M., Funebo, T., Kidman, S., Langton, M., & Sjöholm, I. Effects of combined osmotic and microwave dehydration of apple on texture, microstructure and rehydration characteristics. *LWT- Food Sci Technol.* **34**(2), 95-101 (2001).
8. Izli, N., & Isik, E. Color and microstructure properties of tomatoes dried by microwave, convective, and microwave-convective methods. *Int. J. Food Prop.* **18**(2), 241-249 (2015).
9. Seremet, L., Botez, E., Nistor, O.-V., Andronoiu, D. G., & Mocanu, G.-D. Effect of different drying methods on moisture ratio and rehydration of pumpkin slices. *Food Chem.* **195**, 104-109 (2016).
10. Lüle, F., & Koyuncu, T. Convective and microwave drying characteristics of sorbus fruits (Sorbus domestica L.). *Procedia Soc Behav Sci* **195**, 2634-2643 (2015).
11. Das, C., Das, A., & Golder, A. K. Optimality in microwave-assisted drying of Aloe Vera (Aloe barbadensis Miller) gel using Response Surface Methodology and Artificial Neural Network Modeling. *J. Inst. Eng. India Ser. E.* **97**(2), 143-149. (2016).
12. Ramzi, M., Kashaninejad, M., Salehi, F., Mahoonak, A. R. S., & Razavi, S. M. A. Modeling of rheological behavior of honey using genetic algorithm–artificial neural network and adaptive neuro-fuzzy inference system. *Food Biosci.* **9**, 60-67 (2015).
13. Salehi, F., & Razavi, S. M. Modeling of waste brine nanofiltration process using artificial neural network and adaptive neuro-fuzzy inference system. *Desalin Water Treat.* **57**(31), 14369-14378 (2016).
14. Kamiński, W., Tomczak, E., & Strumill, P. Neurocomputing approaches to modelling of drying process dynamics. *Drying Techn.* **16**(6), 967-992 (1998).
15. Momennazadeh, L., Zomorodian, A., & Mowla, D. Experimental and theoretical investigation of shelled corn drying in a microwave-assisted fluidized bed dryer using Artificial Neural Network. *Food Bioprod Process.* **89**(1), 15-21 (2011).
16. Movagharnejad, K., & Nikzad, M. Modeling of tomato drying using artificial neural network. *Comput Electron Agric.* **59**(1-2), 78-85 (2007).
17. Nikbakht, A. M., Motevali, A., & Minaei, S. Energy and exergy investigation of microwave assisted thin-layer drying of pomegranate arils using artificial neural networks and response surface methodology. *J. Saudi Soc. Agric. Sci.* **13**(2), 81-91 (2014).
18. ASAE. Moisture measurement unground grain and seeds. In. (2007).
19. Ghanbarian, D., Dastjerdi, M. B., & Torki-Harchegani, M. Mass transfer characteristics of bisporus mushroom (Agaricus bisporus) slices during convective hot air drying. *Heat Mass Transfer.* **52**(5), 1081-1088 (2016).
20. Zarein, M., Samadi, S. H., & Ghobadian, B. Investigation of microwave dryer effect on energy efficiency during drying of apple slices. *J. Saudi Soc. Agric. Sci.* **14**(1), 41-47 (2015).
21. Aktaş, M., Khanlari, A., Amini, A., & Şevik, S. Performance analysis of heat pump and infrared–heat pump drying of grated carrot using energy-exergy methodology. *Energy Convers. and Manag.* **132**, 327-338 (2017).
22. Dinani, S. T., Hamdami, N., Shahedi, M., & Havet, M. Mathematical modeling of hot air/electrohydrodynamic (EHD) drying kinetics of mushroom slices. *Energy Convers. Manag.* **86**, 70-80 (2014).
23. Shi, Q., Zheng, Y., & Zhao, Y. Mathematical modeling on thin-layer heat pump drying of yacon (Smallanthus sonchifolius) slices. *Energy Convers. Manag.* **71**, 208-216 (2013).
24. Avhad, M., & Marchetti, J. Mathematical modelling of the drying kinetics of Hass avocado seeds. *Ind Crops Prod.* **91**, 76-87 (2016).
25. Blanco-Cano, L., Soria-Verdugo, A., Garcia-Gutierrez, L., & Ruiz-Rivas, U. Modeling the thin-layer drying process of Granny Smith apples: Application in an indirect solar dryer. *Appl. Therm. Eng.* **108**, 1086-1094 (2016).
26. Mghazli, S., Ouhammou, M., Hidar, N., Lahnine, L., Idlimam, A., & Mahrouz, M. Drying characteristics and kinetics solar drying of Moroccan rosemary leaves. *Renew. Energy* **108**, 303-310 (2017).
27. Kaveh, M., & Amiri Chayjan, R. Modeling thin-layer drying of turnip slices under semi-industrial continuous band dryer. *J. Food Process. Preserv.* **41**(2), e12778 (2017).
28. Jiang, J., Dang, L., Tan, H., Pan, B., & Wei, H. Thin layer drying kinetics of pre-gelatinized starch under microwave. *Taiwan Inst Chem Eng.* **72**, 10-18 (2017).
29. Rabha, D., Muthukumar, P. & Somayaji, C. Experimental investigation of thin layer drying kinetics of ghost chilli pepper (Capsicum Chinense Jacq.) dried in a forced convection solar tunnel dryer. *Renew. Energy* **105**, 583-589 (2017).
30. Koukouch, A., Idlimam, A., Asbik, M., Sarh, B., Izrar, B., Bostyn, S., Amine, A. Experimental determination of the effective moisture diffusivity and activation energy during convective solar drying of olive pomace waste. *Renew. Energy* **101**, 565-574 (2017).
31. Muliterno, M. M., Rodrigues, D., de Lima, F. S., Ida, E. I., & Kurozawa, L. E. Conversion/degradation of isoflavones and color alterations during the drying of okara. *LWT-Food Sci Technol.* **75**, 512-519 (2017).
32. Zhu, A., & Shen, X. The model and mass transfer characteristics of convection drying of peach slices. *Int. J. Heat Mass Transfer.* **72**, 345-351 (2014).
33. Aral, S., & Beşe, A. V. Convective drying of hawthorn fruit (Crataegus spp.): effect of experimental parameters on drying kinetics, color, shrinkage, and rehydration capacity. *Food Chem.* **210**, 577-584 (2016).
34. Minaei, S., Motevali, A., Ahmadi, E., & Azizi, M. H. Mathematical models of drying pomegranate arils in vacuum and microwave dryers. *J. Agric. Sci. Technol.* **14**(2), 311-325 (2012).
35. Darvishi, H., Khoshtaghaza, M. H., Najafi, G., & F. N. Mathematical modeling of green pepper drying in microwave-convective dryer. *J. Agric. Sci. Technol.* **15**, 457-465 (2013).
36. Chayjan, R. A., Kaveh, M., & Khayati, S. Modeling some thermal and physical characteristics of terebinth fruit under semi industrial continuous drying. *J. Food Meas. Charact.* **11**(1), 12-23 (2017a).
37. Khoshtaghaza, M. H., Darvishi, H., & Minaei, S. Effects of microwave-fluidized bed drying on quality, energy consumption and drying kinetics of soybean kernels. *J. Food Sci. Technol.* **52**(8), 4749-4760 (2015).
38. Łechtańska, J., Szadzińska, J., & Kowalski, S. Microwave-and infrared-assisted convective drying of green pepper: Quality and energy considerations. *Chem Eng Process.: Process Intensification* **98**, 155-164 (2015).
39. Pu, Y. Y., & Sun, D. W. Combined hot-air and microwave-vacuum drying for improving drying uniformity of mango slices based on hyperspectral imaging visualisation of moisture content distribution. *Biosyst Eng.* **156**, 108-119 (2017).
40. Hasanipanah, M., Amnich, H. B., Arab, H., & Zamzam, M. S. Feasibility of PSO–ANFIS model to estimate rock fragmentation produced by mine blasting. *Neural. Comput. Appl.* **30**(4), 1015-1024 (2018).
41. Wang, Z., Sun, J., Chen, F., Liao, X., & Hu, X. Mathematical modelling on thin layer microwave drying of apple pomace with and without hot air pre-drying. *J. Food Eng.* **80**(2), 536-544 (2007).
42. Beigi, M. Hot air drying of apple slices: dehydration characteristics and quality assessment. *Heat Mass Transfer.* **52**(8), 1435-1442 (2016).
43. Kaleta, A., Górnicki, K., Winiczenko, R., & Chojnacka, A. Evaluation of drying models of apple (var. Ligol) dried in a fluidized bed dryer. *Energy Convers. Manag.* **67**, 179-185 (2013).
44. Kara, C., & Doymaz, I. Effective moisture diffusivity determination and mathematical modelling of drying curves of apple pomace. *Heat Mass Transfer.* **51**(7), 983-989 (2015).
45. Samadi, S. H., Ghabadian, B., Najafi, G., Motevali, A., & Faal, S. Drying of apple slices in combined heat and power (CHP) dryer: comparison of mathematical models and neural networks. *Chem Prod Process Model* **8**(1), 41-52 (2013).
46. Süfer, Ö., Sezer, S., & Demir, H. Thin layer mathematical modeling of convective, vacuum and microwave drying of intact and brined onion slices. *J. Food Process. Preserv.* **41**, e13239 (2017).

47. Kantrong, H., Tansakul, A., & Mittal, G. S. Drying characteristics and quality of shiitake mushroom undergoing microwave-vacuum drying and microwave-vacuum combined with infrared drying. *J. Food Sci. Technol.* **51**(12), 3594-3608 (2014).

48. Horuz, E., & Maskan, M. Hot air and microwave drying of pomegranate (Punica granatum L.) arils. *J. Food Sci. Technol.* **52**(1), 285-293 (2015).

49. Md Salim, N. S., Gariépy, Y., & Raghavan, V. Hot air drying and microwave-assisted hot air drying of broccoli stalk slices (Brassica oleracea L. var. Italica). *J. Food Process. Preserv.* **41**(3), e12905 (2017).

50. Chayjan, R. A., Kaveh, M., Dibagar, N., & Nejad, M. Z. Optimization of pistachio nut drying in a fluidized bed dryer with microwave pretreatment applying response surface methodology. *Chem Prod Process Model* **12**(3) (2017).

51. Torki-Harchegani, M., Ghasemi-Varnamkhasti, M., Ghanbarian, D., Sadeghi, M., & Tohidi, M. Dehydration characteristics and mathematical modelling of lemon slices drying undergoing oven treatment. *Heat Mass Transfer.* **52**(2), 281-289 (2016).

52. Darvishi, H., Zarein, M., Minaei, S., & Khafajeh, H. Exergy and energy analysis, drying kinetics and mathematical modeling of white mulberry drying process. *Int. J. Food Eng.* **10**(2), 269-280 (2014).

53. Ganesapillai, M., Murugan, P., & Singh, A. Experimental analysis of microwave drying kinetics and characterization of ginger rhizomes. *J. Food Process. Preserv.* **36**(5), 401-411 (2012).

54. Doymaz, İ., Demir, H., & Yildirim, A. Drying of quince slices: effect of pretreatments on drying and rehydration characteristics. *Chem Eng Commun.* **202**(10), 1271-1279 (2015).

55. Doymaz, İ., & Sahin, M. Effect of temperature and pre-treatment on drying and rehydration characteristics of broccoli slices. *J. Food Meas. Charact.* **10**(2), 364-373 (2016).

56. Bal, L. M., Kar, A., Satya, S., & Naik, S. N. Drying kinetics and effective moisture diffusivity of bamboo shoot slices undergoing microwave drying. *Int. J. Food Technol.* **45**(11), 2321-2328 (2010).

57. Darvishi, H., Zarein, M., & Farhudi, Z. Energetic and exergetical performance analysis and modeling of drying kinetics of kiwi slices. *J. Food Sci. Technol.* **53**(5), 2317-2333 (2016).

58. Khanali, M., Banisharif, A., & Rafiee, S. Modeling of moisture diffusivity, activation energy and energy consumption in fluidized bed drying of rough rice. *Heat Mass Transfer.* **52**(11), 2541-2549 (2016).

59. Tripathy, P., Abhishek, S., & Bhadoria, P. Determination of convective heat transfer coefficient and specific energy consumption of potato using an ingenious self-tracking solar dryer. *J. Food Meas. Charact.* **8**(1), 36-45 (2014).

60. Celen, S., & Kahveci, K. Microwave drying behaviour of tomato slices. *Czech J. Food Sci.* **31**(2), 132-138 (2013).

61. Fisk, C. L., Silver, A. M., Strik, B. C., & Zhao, Y. Postharvest quality of hardy kiwifruit (*Actinidia arguta* ‘Ananasnaya’) associated with packaging and storage conditions. *Postharvest Biol. Technol.* **47**(3), 338-345 (2008).

62. Yosefian, S., Razdari, A. M., Seinhoon, M., & Kyani, H. Determination of optimal conditions using response surface method and comparison of neural network and regression method of drying gamma irradiated potato. *Food Sci. Technol.* **13**(59) 85-96 (2017).

63. Tavakolipour, H., Mokhtarian, M., & Kalbasi-Ashtari, A. Intelligent monitoring of zucchini drying process based on fuzzy expert engine and ANN. *J. Food Process Eng.* **37**(5), 474-481 (2014).
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Methodology, V.R.S., R.A. and M.K. Formal analysis, V.R.S., M.K. and M.S. Investigation, V.R.S., R.A. and M.K. Experiment conduction, V.R.S., R.A. and M.K. Statistical Analysis, V.R.S., R.A., M.K. and W.T. Writing original draft preparation, V.R.S., R.A., M.K. and M.S. All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.