MODELING THE DRYING KINETICS OF GREEN BELL PEPPER IN A HEAT PUMP ASSISTED FLUIDIZED BED DRYER

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ABSTRACT

In this research, green bell pepper was dried in a pilot plant fluidized bed dryer equipped with a heat pump humidifier using three temperatures of 40, 50 and 60°C and two airflow velocities of 2 and 3 m/s in constant air moisture. Three modeling methods including nonlinear regression technique, Fuzzy Logic and Artificial Neural Networks were applied to investigate drying kinetics for the sample. Among the mathematical models, Midilli model with R² = 0.9998 and root mean square error (RMSE) = 0.00451 showed the best fit with experimental data. Feed-Forward-Back-Propagation network with Levenberg–Marquardt training algorithm, hyperbolic tangent sigmoid transfer function, training cycle of 1,000 epoch and 2-5-1 topology, deserving R² = 0.99828 and mean square error (MSE) = 5.5E-05, was determined as the best neural model. Overall, Neural Networks method was much more precise than two other methods in prediction of drying kinetics and control of drying parameters for green bell pepper.

PRACTICAL APPLICATIONS

This article deals with different modeling approaches and their effectiveness and accuracy for predicting changes in the moisture ratio of green bell pepper enduring fluidized bed drying, which is one of the most concerning issues in food factories involved in drying fruits and vegetables. This research indicates that although efficiency of mathematical modeling, Fuzzy Logic controls and Artificial Neural Networks (ANNs) were all acceptable, the modern prediction methods of Fuzzy Logic and especially ANNs were more productive and precise. Besides, this report compares our findings with previous ones carried out with the view of predicting moisture quotients of other food crops during miscellaneous drying procedures.

INTRODUCTION

Fluidized bed drying is a novel and efficient method which makes it feasible to dry food products in continuous and moderate conditions. High rate of heat transfer makes drying a thrifty process; on the other hand, no need for various mechanical parts for drying reduces maintaining costs (Wan Daud 2008). It is very difficult to develop a complete mathematical model for predicting dependent variables of a process considering all independent variables. So far, various modeling methods have been applied to forecast drying kinetics of food products in fluidized bed dryers, although their precision and accuracy for predicting moisture losses in different periods of drying processes are dissimilar (Ratti 2009).

A common technique for determination of moisture loss during drying processes is empirical model; at first, various parameters are measured through lab experiments and then, the best algebraic equation for prediction of variables is selected on the basis of fitting lab data with famous algebraic equations. To date, several scientific articles have been published on regression modeling of drying kinetics for various food products e.g., Mota et al. (2010) on onion slices, Ethman Kan et al. (2009) on mint leaves, Doymaz
Nowadays, due to fast development of computer technologies, creation of related software and invention of artificial intelligent technologies including Fuzzy Logic and Artificial Neural Networks (ANNs), it is being made possible to solve complicated problems in relation to systems or process modeling.

Genetic algorithm (GA) is one of the optimization techniques to reach an optimal value of a complex objective function by simulation of biological evolutionary processes based on crossover and mutation (Erenturk and Erenturk 2007). Earlier research have demonstrated that the results for application of various drying methods, mainly convective methods, on different products could be forecasted by GA (Table 1).

Fuzzy Logic is based on fuzzy set theories. This theory has been generalized from classic theories of collections (in mathematics) and functions on the basis of numeral calculations upon created amounts (for each fuzzy variable) by a membership function. Fuzzy rules and logics are backbones of fuzzy interference models. Mamdani fuzzy model is one of the most important modeling tools on the basis of fuzzy set theories (McNeill and Freiberger 1994; Timothy 2010).

ANNs are nonlinear mathematical algorithms and their performance style is similar to the human brain; this technique has been applied for mathematical modeling of independent (input neurons) and dependent (output neurons) variables. The quantity of each hidden neuron is a weighted linear combination of input neurons; output neurons receive an input number from each hidden neuron and transfer function is applied to determine final output quantity. Previous research have proved that application of various drying methods on different products could be predicted very well by ANNs in terms of statistical indices (Table 1).

Fluidized bed dryers are one of the best energy saving dryers. Because there are some constraints for their application on particular and granular materials (e.g., cereals or leguminous), application of these dryers is limited for other crops (e.g., fruits and vegetables). Forecasting kinetics of food drying in these dryers with application of modern modeling techniques including Fuzzy Logic and ANNs, comparison and evaluation of obtained patterns in real conditions seem inevitable to optimize drying conditions and operation costs. The aims of this research were to dry green bell pepper in a custom designed fluidized bed dryer and predict its behavior during drying by three different modeling methods and to compare the accuracy of those models.

### Table 1. Different Studies on Predicting Drying Behavior of Various Food Products by GA and ANNs

<table>
<thead>
<tr>
<th>Food product</th>
<th>Drying method</th>
<th>Modeling technique</th>
<th>Result</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice paddy</td>
<td>Fluidized bed</td>
<td>GA</td>
<td>Efficient to determine the optimal conditions of drying method</td>
<td>(Atthajariyakul and Leephakpreeda 2006)</td>
</tr>
<tr>
<td>Mango</td>
<td>Convective</td>
<td>GA</td>
<td>Better results than empirical and theoretical models</td>
<td>(Vaquiro et al. 2008)</td>
</tr>
<tr>
<td>Corn malt</td>
<td>Convective</td>
<td>GA</td>
<td>GA suggested 54°C and 6 h as the optimum condition</td>
<td>(Curvelo Santana et al. 2010)</td>
</tr>
<tr>
<td>Sesame</td>
<td>Fluidized bed</td>
<td>GA</td>
<td>GA was successfully applied for improving RSM</td>
<td>(Hashemi Shahraki et al. 2014)</td>
</tr>
<tr>
<td>Kiwifruit</td>
<td>Osmo-convective</td>
<td>GA and ANNs</td>
<td>GA was successfully applied for optimization of the ANNs' parameters</td>
<td>(Fathi et al. 2011)</td>
</tr>
<tr>
<td>Carrot</td>
<td>Convective</td>
<td>GA and ANNs</td>
<td>RSM and GA were successfully applied to find the optimum topology of ANNs</td>
<td>(Aghbashlo et al. 2011)</td>
</tr>
<tr>
<td>Blueberries</td>
<td>Osmo-convective</td>
<td>ANNs</td>
<td>Much better performance than mathematical models</td>
<td>(Chen et al. 2001)</td>
</tr>
<tr>
<td>Grains</td>
<td>Intermittent</td>
<td>ANNs</td>
<td>High performance in terms of various statistical indices</td>
<td>(Jumah and Mujumdar 2005)</td>
</tr>
<tr>
<td>Turnip seeds</td>
<td>Vibro-Fluidized bed</td>
<td>ANNs</td>
<td>High fitting rates were achieved</td>
<td>(Alvarez et al. 2005)</td>
</tr>
<tr>
<td>Tomato</td>
<td>Tray</td>
<td>ANNs</td>
<td>More accurate than mathematical equations</td>
<td>(Movagharnejad and Nikzad 2007)</td>
</tr>
<tr>
<td>Pomegranate juice</td>
<td>Spray</td>
<td>ANNs</td>
<td>3-10-8-5 topology was the best one</td>
<td>(Youssefi et al. 2009)</td>
</tr>
<tr>
<td>Paddy</td>
<td>Fluidized bed</td>
<td>ANNs</td>
<td>7-1-3-7-1 topology was the best one</td>
<td>(Chichan Amiri et al. 2009)</td>
</tr>
<tr>
<td>Grains</td>
<td>Fixed bed</td>
<td>ANNs</td>
<td>Successful to determine the moisture distribution</td>
<td>(Farkas 2013)</td>
</tr>
<tr>
<td>Carrot</td>
<td>Fluidized bed</td>
<td>ANNs</td>
<td>Training and validation stages of ANNs had a strong influence on its applicability</td>
<td>(Nzaghelichi et al. 2011)</td>
</tr>
<tr>
<td>Canola</td>
<td>Fluidized bed</td>
<td>ANNs</td>
<td>Much better performance than mathematical models</td>
<td>(Malekjani et al. 2013)</td>
</tr>
</tbody>
</table>

ANNs, artificial neural networks; GA, genetic algorithms.


Fluidized bed dryers are one of the best energy saving dryers. Because there are some constraints for their application on particular and granular materials (e.g., cereals or leguminous), application of these dryers is limited for other crops (e.g., fruits and vegetables). Forecasting kinetics of food drying in these dryers with application of modern modeling techniques including Fuzzy Logic and ANNs, comparison and evaluation of obtained patterns in real conditions seem inevitable to optimize drying conditions and operation costs. The aims of this research were to dry green bell pepper in a custom designed fluidized bed dryer and predict its behavior during drying by three different modeling methods and to compare the accuracy of those models.

\[1\] Activation function.
MATERIALS AND METHODS

Pilot Plant Fluidized Bed Dryer Apparatus

A pilot plant fluidized bed dryer having closed airflow circulation and equipped with a heat pump dehumidifier system was applied for drying green bell pepper. According to Fig. 1, different parts of the system were fixed in a frame with $170 \times 80 \times 90$ cm$^3$ dimensions. The system included a vane centrifuge blower (2 hp power) equipped with a frequency inverter (SVO 15IC5, Seoul, Korea) in order to set the intensity of input airflow. The moisture controller system was made of a compressor, a condenser and an evaporator, which could regulate the entrance of moisture within the machinery. The drying chamber was made of Plexiglas and had 20 cm diameter and 60 cm height. On arrival, middle and terminal parts of the machinery, precise sensors of airflow moisture (SIWAN moisture tester, K200, Taipei, Taiwan), temperature (ATBIN digital thermostat, 915055, Tehran, Iran) and velocity were fixed; sensors were equipped with cascade-forward programs and could set conditions if unwanted changes occurred. There were other sensors inside tubes, on conjunction points and after the condenser to control all parts of the machine.

As opposed to current systems which have open airflow circulation and no dehumidifier system, in our designed dryer, waste of energy could be kept at minimal rates and there is no need for such a long time or much energy to heat drying air (Ratti 2009).

Drying Material and Method

Fresh bell peppers were purchased from a local market in Gorgan (Iran). Samples were transported to lab after packaging in nyons and held in the refrigerator. Initial moisture of samples was measured 91.4% (w.b.) using the Official Methods of Analysis (Association of Official Analytical Chemists 1999). For each drying treatment, some peppers were taken out from nyons and cut into slices with 10 mm length, 10 mm width and 1.5 mm thickness by a sharp knife after removing their tail and white seeds. An amount of 50 g (on average) of samples was weighed by a digital balance (GK1203, Sartorius Co., Göttingen, Germany), displaced to the feed disk of drying apparatus and dried. During the process, every 10 min, the samples were removed, weighed (to analyze moisture content) and re-dried till there was less than 0.1 g difference between two consecutive weight measurements. In this stage, moisture of samples was measured again and considered as equilibrium moisture. Measured weights were converted to moisture ratios by the following equation

\[
MR = \frac{M - M_e}{M - M_0} \tag{1}
\]

FIG. 1. A PILOT PLANT FLUIDIZED BED DRYER EQUIPPED WITH A MOISTURE CONTROLLER SYSTEM
where MR, M₀, and M are moisture ratio (dimensionless), moisture content (d.b.), initial moisture content (d.b.) and equilibrium moisture content (d.b.), respectively.

### Regression Modeling

Curve fitting tool of MATLAB 7.10 (Mathworks, Inc., Natick, MA) and nonlinear regression technique were applied to fit experimental moisture ratio data with predicted ones by mathematical models; constant coefficients and evaluation factors of applied mathematical models were estimated properly. Mathematical models were compared on the basis of three well-known statistical factors including correlation coefficient (R), root mean square error (RMSE) and sum of squares error (SSE). Among the presented models, a model with maximum R and minimum RMSE and SSE was selected as the best model to forecast the drying process. Table 2 represents applied mathematical models.

### Modeling with Application of Fuzzy Logic

Simulation of experimental moisture ratio data was carried out with Fuzzy Logic tool in MATLAB and Mamdani method under If–Then fuzzy rules for two input and an output variables. Therefore, moisture ratios after certain periods of time (every 10 min) were simulated on the basis of drying airflow temperature in three levels with fuzzy terms of “low” for temperature of 40°C, “medium” for temperature of 50°C and “high” for temperature of 60°C and drying airflow velocity in two levels with fuzzy terms of “low” for velocity of 2 m/s and “high” for velocity of 3 m/s. Final moisture ratio was obtained from six applied temperature–time treatments i.e., 40°C–2 m/s, 40°C–3 m/s, 50°C–2 m/s, 50°C–3 m/s, 60°C–2 m/s and 60°C–3 m/s with fuzzy terms of “very high”, “high”, “medium”, “low”, “very low” and “very very low” (respectively). Triangular membership functions were applied for setting some changes in three variables i.e., temperature, velocity and moisture ratio. A triangular membership function with three parameters of {a, b, c} was defined by following equation (Akpinar 2006)

\[
\text{Triangle}(x; a, b, c) = \begin{cases} 
0 & x \leq a \\
\frac{x-a}{b-a} & a \leq x \leq b \\
\frac{c-x}{c-b} & b \leq x \leq c \\
0 & c \leq x 
\end{cases}
\]

(2)

Interpolation was done by extracting moisture ratios from fuzzy interference and three-dimensional (3D) surface plots for every 1 degree change in the range of 40–60°C and for different drying times at two air velocities of 2 and 3 m/s.

### Modeling with Application of ANNs

Neural Networks having two neurons for their input layer (time and airflow temperature) and a neuron for output layer (moisture ratio) were designed for two different air velocities of 2 and 3 m/s by applying interpolation results extracted from fuzzy modeling. After trial and error, network unit with Feed-Forward-Back-Propagation structure, hyperbolic tangent sigmoid transfer function for neurons of hidden layer, linear transfer function for neuron of output layer, Levenberg–Marquardt training algorithm on the basis of hessian matrix and training cycle of 1,000 epoch with assistance of two evaluation factors i.e., R and mean square error (MSE), were selected. Besides, through the process, 60% of the data were applied for training, 15% for validation and 25% for test of selected networks. The best topology (with the highest R and the least MSE) was selected for fluidized bed drying process of green bell pepper by changing number of hidden layers and number of neurons for each layer.

Optimum transfer function for each neuron of hidden layers was hyperbolic tangent sigmoid transfer function (Eq. 3) for two consecutive layers of i and j:

\[
Y_j = \frac{2}{(1+\exp(-2x_j))} - 1 
\]

(3)

Yᵢ was the output of neuron number j and Xᵢ was the sum of weighted inputs for each neuron of layer number j; the latter parameter was calculated according to Eq. (4):

\[
\sum \alpha_i(x_i) 
\]

(4)

---

**TABLE 2. MATHEMATICAL MODELS APPLIED FOR REGRESSION MODELING OF DRYING KINETICS FOR GREEN BELL PEPPER IN A FLUIDIZED BED DRYER**

<table>
<thead>
<tr>
<th>Model number</th>
<th>Model name</th>
<th>Model equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Newton</td>
<td>MR = \exp(-kt)†</td>
</tr>
<tr>
<td>2</td>
<td>Logarithmic</td>
<td>MR = \exp(-kt) + c</td>
</tr>
<tr>
<td>3</td>
<td>Page</td>
<td>MR = \exp(-kt)</td>
</tr>
<tr>
<td>4</td>
<td>Two-term exponential</td>
<td>MR = \exp(-kt) + (1-a) \exp(-kat)</td>
</tr>
<tr>
<td>5</td>
<td>Wang and Singh</td>
<td>MR = 1 + at + bt²</td>
</tr>
<tr>
<td>6</td>
<td>Approximation of diffusion</td>
<td>MR = \exp(-kt) + (1-a) \exp(-ktb)</td>
</tr>
<tr>
<td>7</td>
<td>Modified Henderson and Pabis</td>
<td>MR = \exp(-kt) + b \exp(-gt) + c \exp(-ht)</td>
</tr>
<tr>
<td>8</td>
<td>Midilli–Kucuk</td>
<td>MR = \exp(-kt') + bt</td>
</tr>
<tr>
<td>9</td>
<td>Henderson and Pabis</td>
<td>MR = \exp(-kt)</td>
</tr>
</tbody>
</table>

† k, g and h are model constants in the units of (min⁻¹) and a, b, c, d, e and f are dimensionless constants of mentioned models. MR, moisture ratio.
DRYING KINETICS OF GREEN BELL PEPPER

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If (Tem is low) and (Vel is low) then (MR is VH)  
If (Tem is low) and (Vel is high) then (MR is H)  
If (Tem is medium) and (Vel is low) then (MR is M)  
If (Tem is medium) and (Vel is high) then (MR is L)  
If (Tem is high) and (Vel is low) then (MR is VL)

FIG. 2. MAMDANI METHOD UNDER SIX IF–THEN FUZZY RULES FOR TWO INPUTS (TEMPERATURE; TEM AND VELOCITY; VEL) AND AN OUTPUT (MOISTURE RATIO; MR) VARIABLE

VH: Very High; H: High; M: Medium; L: Low; VL: Very Low; VVL: Very Very Low.

Experimental Design and Data Analysis

Different treatments were designed for three levels of airflow temperature (40–50–60°C), two levels of airflow velocity (2 and 3 m/s) and constant dimensions of sample (1.5 × 10 × 10 mm) at a completely randomized factorial design with three replications. Data analysis and mean comparison were performed with application of Statistica 9.0 (Statsoft, Tulsa, OK) and Duncan’s test in the level of P < 0.05, respectively. EXCEL software (Microsoft, New York) was applied for plotting data.

RESULTS AND DISCUSSION

Regression Modeling for Drying Kinetics of Green Bell Pepper

Curves of moisture ratio against time were plotted for different conditions of drying to investigate drying kinetics and mechanisms of moisture transfer (Fig. 2).

By the increase of airflow temperature from 40 to 60°C, slope of curve was increased. A similar trend was also observed by the increase of airflow velocity from 2 to 3 m/s; the effect of two parameters on drying rate was statistically significant (P < 0.05). Obviously, the effect of velocity was too negligible compared with the effect of temperature. In other words, the most effective factor on the drying rate of green bell pepper was temperature. Akpinar (2006) and Mota et al. (2010) reported temperature as the most effective factor on thin-layer drying of some fruits and vegetables, too. Trend of changes in moisture ratio versus time implies that our sample lost the largest part of its moisture in the period of descending velocity and the dominating mechanism of moisture transfer in the drying course was vapor diffusion (Chen and Mujumdar 2008).

Table 3 represents evaluation factors obtained by fitting experimental moisture ratio data with mathematical models. The Midilli model with R² = 0.9999, RMSE = 0.00451 and SSE = 0.000264 was the best one to describe drying kinetics for green bell pepper. The Midilli model had also been introduced as the best one to describe drying behavior of some other agricultural crops such as onion and apple slices (Meisamiasl et al. 2010; Mota et al. 2010). By considering constants and factors of the Midilli model (a = 0.9985, b = −0.0001, k = 0.0545, n = 0.8591), the following equation could be successfully applied for predicting the moisture ratio of green bell pepper at different stages of the fluidized bed drying process:

\[ MR = 0.9985\exp(-0.0545(0.8591)^t) - 0.0001 \]

In order to evaluate the validity of the selected model (Midilli model), moisture ratio experimental data obtained during the drying process were compared with forecasted ones by the Midilli model (Fig. 3). The points were located on the 45° straight line deserving very a high rate of correlation (R = 0.999); therefore, it can be concluded that the Midilli model was suitable for predicting drying kinetics of green bell pepper.

Modeling Drying Kinetics for Green Bell Pepper by Applying Fuzzy Logic

In order to simulate the drying process of green bell pepper, triangular membership function was designed for setting temperature, velocity and moisture ratio changes in periodic times of 10 min by application of Fuzzy Logic tool in MATLAB. Figure 4 represents a sample of membership functions at the 50th min of drying process.

The results of simulating moisture ratio data were depicted in terms of fuzzy interference and 3D surface plots by Fuzzy Logic tool. Figure 5 represents two plots of drying process at the 50th and 100th min.

Fuzzy interference plots give an outline of fuzzy modeling process and indicate effects of each membership function on final results, individually. In the plots, each row and column is related to an If–Then rule and a variable, respectively. For example, regarding the fuzzy interference plots (Fig. 5), moisture ratio of 0.0589 will be obtained at 45°C and 2.8 m/s after 100 min of the drying process. In order to evaluate accuracy of interpolation and confirm the obtained fuzzy model, moisture ratio data for treatments with 2 m/s–50C and 3 m/s–50C conditions were extracted from fuzzy interference plots and compared with experimental ones (Fig. 6). High correlation of those data displayed high level of accuracy for selected fuzzy model.
Alvarez-Lopez et al. (2005), Vaquiro et al. (2008), Perrot et al. (2006) and other researchers have mentioned high correlation between the data obtained from Mamdani fuzzy model and measured ones during drying processes of different products.

Modeling Drying Kinetics of Green Bell Pepper by Applying ANNs

Table 4 represents comparison between the effects of hidden layers number and neurons number in each hidden layer on precision of predicting moisture ratios in different times and temperatures of drying at 2 and 3 m/s airflow velocities. Feed-Forward-Back-Propagation network with Levenberg–Marquardt training algorithm, hyperbolic tangent sigmoid transfer function and 2-5-1 topology deserved the maximum R (0.99914) and minimum MSE (0.000054825). Islam et al. (2003) reported that one layer topology indicated the best topology for drying tomato slices, too. Generally, Feed-Forward-Back-Propagation neural networks with Levenberg–Marquardt training algorithm and topologies with just one hidden layer have shown to be the best neural models for predicting drying kinetics of different fruits and vegetables.

As weight matrix between input and hidden layer, a hessian matrix was created with connecting two neurons of input layer into five neurons of hidden layer as follows

\[
\begin{pmatrix}
4.670 & 9.043 & -1.973 & 2.936 & 1.625 \\
-3.034 & -0.907 & 0.046 & -0.328 & 0.827 \\
0.008 & 0.035 & 4.198 & 0.574 & -0.504
\end{pmatrix}
\]

As weight matrix between hidden and output layers, a hessian matrix was created with connecting five neurons of hidden layer into a neuron of output layer as shown below

\[
\begin{pmatrix}
4.670 & 9.043 & -1.973 & 2.936 & 1.625 \\
-3.034 & -0.907 & 0.046 & -0.328 & 0.827 \\
0.008 & 0.035 & 4.198 & 0.574 & -0.504
\end{pmatrix}
\]
Bias had a format of $5 \times 1$ hessian matrix from input layer into hidden layer and $1 \times 1$ hessian matrix from hidden layer into output layer:

$$
\begin{pmatrix}
-2.154 \\
-0.108 \\
-2.628 \\
2.287 \\
1.405
\end{pmatrix}
\text{(3.806)}
$$

Hereby, network output (moisture ratio) can be calculated by selection of every arbitrary input (drying time and temperature) for each velocity (2 or 3 m/s).

To validate 2-5-1 topology as the best configuration for modeling bell pepper drying, predicted moisture ratio data were plotted against experimental ones during the whole period of drying process. As it can be seen in Figs. 7 and 8, all points were located near a $45^\circ$ straight line with a very high correlation coefficient.
Comparison of Three Modeling Methods

Regression model is a fairly complicated mathematical method, which can just indicate changes in moisture ratios as a function of time on the basis of a series of factors; it can not specify complicated nonlinear relationships between internal and external variables of process. Furthermore, because in this method some series of data fail to get benefit of any training algorithms, the system is not capable of forecasting engaged processes with high probability. Fuzzy
model can relate internal and external variables of processes with application of fuzzy interferences and 3D surface plots on the basis of If–Then rules; this model is stronger than empirical models of training aspect, but it has not enough efficiency to predict moisture ratio data relating temperature and velocity extent out of predefined ranges. In other words, fuzzy system is a useful technique for interpolation and to increase experimental data for final application in more complicated modeling methods e.g., ANNs. On the other hand, Neural Network models are not only capable of

### Table 4. Monitoring the Effects of Hidden Layers Number and Nodes Number for Each Layer on Precision of Moisture Ratio Predicting at 2 and 3 m/s by ANNs

<table>
<thead>
<tr>
<th>Number of hidden layer nodes</th>
<th>Air velocity of 2 m/s</th>
<th>Air velocity of 3 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>MSE</td>
</tr>
<tr>
<td>2</td>
<td>0.99829</td>
<td>0.0000088798</td>
</tr>
<tr>
<td>3</td>
<td>0.99830</td>
<td>0.000131630</td>
</tr>
<tr>
<td>4</td>
<td>0.99899</td>
<td>0.0001065180</td>
</tr>
<tr>
<td>5</td>
<td>0.99892</td>
<td>0.000073530</td>
</tr>
<tr>
<td>6</td>
<td>0.99907</td>
<td>0.000104780</td>
</tr>
<tr>
<td>1</td>
<td>0.98801</td>
<td>0.0000615220</td>
</tr>
<tr>
<td>2</td>
<td>0.60586</td>
<td>0.022348000</td>
</tr>
<tr>
<td>3</td>
<td>0.99904</td>
<td>0.000075920</td>
</tr>
<tr>
<td>1</td>
<td>0.98817</td>
<td>0.0000805560</td>
</tr>
<tr>
<td>1</td>
<td>0.98819</td>
<td>0.0000992600</td>
</tr>
<tr>
<td>2</td>
<td>0.99854</td>
<td>0.000135900</td>
</tr>
<tr>
<td>3</td>
<td>0.98805</td>
<td>0.001028300</td>
</tr>
<tr>
<td>2</td>
<td>0.98729</td>
<td>0.001176300</td>
</tr>
<tr>
<td>3</td>
<td>0.99922</td>
<td>0.000074330</td>
</tr>
<tr>
<td>1</td>
<td>0.98756</td>
<td>0.000984660</td>
</tr>
<tr>
<td>1</td>
<td>0.98813</td>
<td>0.001068400</td>
</tr>
<tr>
<td>1</td>
<td>0.98709</td>
<td>0.001174000</td>
</tr>
<tr>
<td>2</td>
<td>0.044787</td>
<td>0.035521000</td>
</tr>
<tr>
<td>2</td>
<td>0.03448</td>
<td>0.036295000</td>
</tr>
<tr>
<td>3</td>
<td>0.61505</td>
<td>0.020246000</td>
</tr>
<tr>
<td>2</td>
<td>0.99913</td>
<td>0.000067463</td>
</tr>
</tbody>
</table>

Best fitting conditions are in boldface.

ANNs, artificial neural networks; R, correlation coefficient; MSE, mean square error.

**FIG. 7.** MOISTURE RATIO DATA PREDICTED BY FUZZY MODEL VERSUS THE EXPERIMENTAL ONES AT 50°C AND AIR VELOCITY OF (A) 2 M/S OR (B) 3 M/S FOR GREEN BELL PEPPER

**FIG. 8.** MOISTURE RATIO DATA PREDICTED BY ANNs AT THE BEST TOPOLOGY (2-5-1) VERSUS THE EXPERIMENTAL ONES DURING FLUIDIZED BED DRYING PROCESS OF GREEN BELL PEPPER
relating internal and external variables, but also able to characterize all possible interactions among internal variables. Neural Network models could be managed to develop by application of multiple training algorithms; moreover, because series of data pass through training, validation and test stages, the R between experimental and forecasted data is increased and MSE is decreased. Previous applications of ANNs for predicting product behavior during drying have led to a high fitting rate for final selected topology (Table 5).

**CONCLUSIONS**

Three modeling methods including regression technique, Fuzzy Logic and ANNs were appropriate to forecast the drying behavior of green bell pepper during fluidized bed drying. Midilli model could be entitled as a model with the highest performance \((R = 0.9999, \text{RMSE} = 0.00451\) and \(\text{SSE} = 0.000264\)) among mathematical models to predict moisture ratios at different drying conditions. Very high correlation between the data obtained from Mamdani fuzzy model and experimental ones during drying processes displayed high level of accuracy in selecting fuzzy model. The interpolation results of fuzzy model, having maximum correlation with experimental data \((R = 1)\) among three modeling methods, could be used to increase moisture ratio data theoretically and train Neural Networks. A Neural Network with Feed-Forward-Back-Propagation structure, Levenberg–Marquardt training algorithm, hyperbolic tangent sigmoid transfer function and topology of 2-5-1, by a correlation coefficient of 0.99914 and a MSE of 0.00054825, deserved the highest fidelity among different applied topologies and all other models to forecast drying kinetics of green bell pepper.

**REFERENCES**


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