Comparison of Mathematical Equation and Neural Network Modeling for Drying Kinetic of Mendong in Microwave Oven

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Abstract. Mendong (Fimbristylis globulosa) has a potentially industrial application. We investigate a predictive model for heat and mass transfer in drying kinetics during drying a Mendong. We experimentally dry the Mendong by using a microwave oven. In this study, we analyze three mathematical equations and feed forward neural network (FNN) with back propagation to describe the drying behavior of Mendong. Our results show that the experimental data and the artificial neural network model has a good agreement and better than a mathematical equation approach. The best FNN for the prediction is 3-20-1-1 structure with Levenberg-Marquardt training function. This drying kinetics modeling is potentially applied to determine the optimal parameters during mendong drying and to estimate and control of drying process.

1. Introduction
Mendong grass (popular name in Java Indonesia) is scientifically known as Fimbristylis globulosa and comes from family Cyperaceae. It is grown mostly in the wet tropical forest climate which is within area that have a height of 300-700 m above sea level [1]. In Indonesia, mendong grass is grown widely in several island such as Java, Sumatra, Kalimantan, and Sulawesi. The main crop of mendong grass is the stem or stalk and referred to as mendong. Upon harvesting of mendong grass, fresh mendong stem has a water content of 52% at the base, and 42% in the middle of the stem [2]. In drying process, mendong with high moisture simultaneously involves heat and mass transfer, where water is transferred by diffusion from inside of materials towards the air by convection. The processed mendong is the basic material for woven handicraft, such as mats, baskets, bags, and hats.

Drying of agricultural products is greatly importance to the preservation of postharvest materials by human being. Sun-drying is still the most common method to preserve agricultural products in most tropical and subtropical countries. Over the time, a lot of research on the drying process for agricultural postharvest have been studied. Some dryers that have been produced and in designing process are solar cabinet dryer [3], recirculated tray dryer [4], and the experimental device Batch type dryer [5].

Drying is widely used in the food processing industry and grow into a major process in postharvest product processing. Drying process in a microwave oven has an advantage in terms of drying rate, energy efficiency, product quality, and efficiency in the utilization of space [6]. Several studies have been conducted to test the drying process of agricultural products through the use of microwave heating, such as the foot elephan yan (Amorphophallus paeonifolius) [6], carrots [7], lemon [8], and durian [9].

The product drying results certainly lose all the water in the material, consequently its moisture, humidity, color, texture, and others parameter change compared to fresh produce postharvest. The results of drying process physically changes, however the material quality should follows the standards
production process. The standard process for drying is determined through testing the whole process in drying. Modeling of drying kinetic is preferred to describe the whole process of drying product.

The aim of this study is, 1) to determine the influence of microwave oven power on drying kinetic during microwave heating and 2) investigate a model of drying kinetic based on both mathematical equation and artificial neural network for mendong. The drying experiment are performed in different experimental conditions.

2. Materials and Methods

2.1. Materials
Fresh mendong grass which grows in the Manonjaya mendong paddies of Tasikmalaya, East Java, Indonesia, were collected after harvest. The mendongs part were used for experiment are stems with length from 1 to 1.2 m. The selected mendongs cut into a length of 10 cm ±0.5 cm using stainless steel scissor. A group of sample are mendong with same dimensions (diameter and length) from a single stem, each obtained 7 to 11 pieces. Measuring the diameter and length of mendongs were using calipers (Pudak Scientific, Indonesia) with accuracy 0.05 mm. The entire sample washed to remove dust and other foreign materials by water and stored in a refrigerator at temperature of 10 ±1°C for preventing from moisture losses. The initial moisture content of the sample was determined by drying in a convective oven (Midea) at temperature of 105 ±1°C until the weight did not change any more [6]-[8]. The initial moisture content of the samples was about 78.44% wb (wet basis).

2.2. Drying Procedure
The method was obtained for drying experiment is periodic sampling or weighing [10]. The samples were measured at certain time interval and its moisture content determined by laboratory methods. This method is considered as the most effective way to observe the drying rate for this experiment.

The drying experiments were performed using a microwave oven (LG MS2329H, South Korea), with 1000 Watt of power consumption. The microwave was operated at different power levels. Initial mass of samples was weighed using a digital balance (Boeco, Germany) with an accuracy of ± 0.01 g. The moisture loss of samples during drying weighed and recorded within 2 minutes ± 2 seconds. The temperature changes in the sample was also measured using a digital thermometer (Blue Gizmo) with accuracy ± 0.1°C.

Microwave oven during this experiment was operated at four power levels as described. The fourth power levels was calculated using the IMPI 2-liter test Buffler [9]. On this test, the microwave oven was operated at its rated line voltage with load of 2000 ±5 g placed in two 1L beakers (Pyrex 1000) at an initial water temperature of 20 ± 2°C. The beakers were placed in the center of the microwave oven. The microwave oven was turned on for 2 minutes ± 2 seconds. Then the beakers were removed from the microwave oven. The final temperatures were measured and recorded. The power was calculated as follows:

\[ P(W) = 70 \left( \frac{\Delta T_1 + \Delta T_2}{2} \right) \]  

(1)

Where \( P(W) \) was microwave oven power, \( \Delta T_1 \) and \( \Delta T_2 \) was the temperature rise of the water in the first and second beakers, calculated by subtracting the initial water temperature from the final temperature, respectively.

In this study, the microwave oven was operated at four levels, being 575, 600, 700, and 800 Watt, respectively, for keep warm, medium low, medium, and medium high level.

2.3. Mathematical Modeling of Drying Kinetic
There are several mathematical equations in literatures that describe drying phenomena of agricultural products. Each equation of models is categorized as: a) theoretical models, suggest that the moisture transport is controlled mainly by internal moisture mechanism and needs assumption of geometry of the
food material, mass diffusivity and heat conductivity [6]; b) semi theoretical models, consider only the external resistance to the moisture transport and are valid only in the specific range drying conditions [5]; and c) empirical models, derive a direct relationship between average moisture content and drying time, they neglect fundamentals of the drying process and their parameters have no physical meaning [6].

During the drying process, diffusivity is assumed to be the only physical mechanism for the transfer of water to material surface and can be defined by Fick’s second law of diffusion as follows [7]:

$$\frac{\partial M}{\partial t} = D_{\text{eff}} \frac{\partial^2 M}{\partial x^2}$$

(2)

Kinetic models are commonly developed based on the moisture ratio (MR) normally characterized by centering attribute and better illustration. MR is defined as Eq. (3) [11]:

$$MR = \frac{M_t - M_e}{M_0 - M_e}$$

(3)

Where $M_t$ is the moisture content ($kg_{\text{water}} kg_{\text{dry mater}}^{-1}$) and $M_e$ and $M_0$ are equilibrium and primary moisture contents, respectively. Considering a negligible value of $M_e$ with respect to $M_0$ and $M_t$, the error of eliminating $M_e$ from Eq. (3) can be ignorable. Thus, Eq. (3) can be written as Eq. (4) [11]:

$$MR = \frac{M_t}{M_0}$$

(4)

The mathematical equations are used to describe the drying behavior of natural materials. These equation may be considered as oversimplified solutions of the diffusion equation [12]. The original solution is a simple exponential equation and is known as Newton’s equation. However the original equation has been modified by several studies to fit the experimental data. Table 1 consists of three mathematical equations that empirically describe the drying rate on agricultural products.

| No | Model Name          | Mathematical Function              |
|----|---------------------|------------------------------------|
| 1  | Wang and Singh      | $MR = at^2 + bt + c$              |
| 2  | Henderson and Pabis | $MR = a \exp(-kt)$                |
| 3  | Newton              | $MR = \exp(-kt)$                  |

The regression analysis was performed using 2D table curve. The mean square error ($MSE$), mean relative percent error ($P$), and correlation coefficient ($R^2$) are the criterions for selection of the best equation in each experimental condition [6],[8],[12],[13]. $MSE$, $P$, and $R^2$ are calculated as follows:

$$MSE = \frac{\sum_{i=1}^{N} (MR_{\text{pred},i} - MR_{\text{exp},i})^2}{N - N_p}$$

(5)

$$P = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{MR_{\text{pred},i} - MR_{\text{exp},i}}{MR_{\text{exp},i}} \right|$$

(6)
\[
R^2 = 1 - \frac{\sum_{i=1}^{N} (M_{i}^{\text{pre},i} - M_{i}^{\text{exp},i})^2}{\sum_{i=1}^{N} (M_{i}^{\text{exp},i})^2}
\]  
(7)

Where \( M_{i}^{\text{exp},i} \) stands for the experimental moisture ratio found in any measurement and \( M_{i}^{\text{pre},i} \) is the moisture ratio predicted for this measurement. \( N \) and \( N_p \) are the number of observation and number of model parameters, respectively. Modeling of drying rate using the mathematical equations provide accurate results for some specific experiments. However, modeling of drying rate using mathematical equations cannot be generalized for all conditions, therefore no general equation for modeling drying rate. Those problems can be solved by using an analytic model drying [12].

2.4. Artificial Neural Network

2.4.1. Artificial Neural Network for This Study

Artificial neural networks (ANN) are systems whose structure is inspired by the action of the nervous system and the human brain [13]. ANN majorly used to predict the processes in the processing of agricultural products. Several previous studies have predicted and modeled the drying rate of some postharvest products, such as, dill leaves [11], tomatoes [12], grape [13], and cassava and mango [15].

The type of network used in this study is the multi-layer perceptron network. Multi-layer perceptron network are one of the most popular and successful neural network architectures, which are widely applied such as prediction and process modeling [12].

In learning process of ANN, we specified the model as follows: 1) ANN architecture that will be used; 2) Data input and targets; 3) the number of sets of data to be trained; 4) the number of layers and neurons; 5) activation function; 6) learning function that will be used; 7) initialization of synaptic weights and bias for each neuron; and 8) the amount of the maximum epoch. Moreover, at each step of the design described in more detail in next section.

2.4.2. Feed Forward Neural Network with Backpropagation

The type of network that used for modeling is a feedforward neural network (FNN). FNN is type of neural network which the connection between neurons is only in one direction. The structure consists of several layers (multi-layers) with inter-layer connection in the forward direction. These layers consist of the input layer, a hidden layer, and the output layer.

Figure 1 illustrates the structure of a FNN with back propagation model for predicting the moisture ratio and drying rate of mendong. The different networks with different amounts of layers are used for this modeling. The dimensions of the input and output matrix are 3x279 and 1x279, respectively. The total amounts of the network input patterns are 279, which first were normalized and then were randomly divided into three groups, namely training (80%), validation (10%), and testing (10%). The dimension of the matrix for training, validation, and testing pattern are 3 x 223, 3 x 28, and 3 x 28, respectively. Various threshold function, such as sigmoid (logsig), logarithmic (tansig), and linear (purelin), were used. Supervised learning algorithms such as trainlm algorithm (Levenberg-Marquardt), and traingdx
were used and their result were compared to determine the best structure for predicting the thin layer drying of mendong.

Feedback backpropagation method was chosen as the method which used for error correction on this FNN structure. Normally, the backpropagation method is the first order gradient method to train neural networks to correlate between input and output variables. The backpropagation network consist of two phases, a forward pass during the processing occurs from the input layer to the output and a backward pass when the error from the output layer is propagated back to the input layer [12].

3. RESULT AND DISCUSSION

![Figure 2. Various of moisture ratio with time for mendong sample under different microwave power](image)

The moisture ratio versus drying time for the mendong sample at the selected microwave powers is shown in Fig. 2. As indicated by the curve in this figure, with increasing drying power the amount of moisture removed from mendong sample increased, and the time to achieved minimum value of moisture ratio in finished products was reduced. The time required for the lowering of moisture content of mendong sample to minimum value from level 78.44% wb varied between 8 and 26 minute, depending on the microwave power level. The results indicate that a higher microwave power causes a rapid mass transfer within the sample. Similar result were reported by other researches [8], [11]
### Table 1. Statistical parameter from fitting the experimental data to the mathematical models at different microwave oven power

| Power Level | Model Name       | Coefficient and Constant | $R^2$  | P    | MSE   |
|-------------|------------------|--------------------------|--------|------|-------|
| 575         | Wang & Singh     | $a = 0.001$  $b = -0.0599$  $c = 1.0546$ | 0.9897 | 0.0654 | 0.0029 |
|             | Henderson & Pabis | $a = 1.1013$  $k = 0.072$    | 0.9786 | 0.0728 | 0.0038 |
|             | Newton           | $k = 0.067$            | 0.9713 | 0.0793 | 0.0054 |
| 605         | Wang & Singh     | $a = 0.0083$  $b = -0.171$  $c = 1.2073$ | 0.9908 | 0.2008 | 0.0106 |
|             | Henderson & Pabis | $a = 0.9246$  $k = 0.171$    | 0.9146 | 0.0521 | 0.0012 |
|             | Newton           | $k = 0.18$            | 0.9109 | 0.0498 | 0.0008 |
| 700         | Wang & Singh     | $a = 0.0146$  $b = -0.2265$  $c = 1.0109$ | 0.9787 | 0.0254 | 0.0004 |
|             | Henderson & Pabis | $a = 0.7935$  $k = 0.18$    | 0.8180 | 0.0493 | 0.0027 |
|             | Newton           | $k = 0.212$            | 0.7814 | 0.0469 | 0.0014 |
| 800         | Wang & Singh     | $a = 0.0218$  $b = -0.2699$  $c = 0.9924$ | 0.9902 | 0.0156 | 0.0002 |
|             | Henderson & Pabis | $a = 0.7882$  $k = 0.201$    | 0.8187 | 0.0355 | 0.0022 |
|             | Newton           | $k = 0.241$            | 0.7705 | 0.0386 | 0.0012 |

#### Figure 3. Comparison between the experimental moisture ratio and those predicted by the Wang and Singh model

The moisture contents of mendong samples at different microwave powers were converted to the moisture ratio ($MR$) and fitted to the three mathematical equation for drying models listed in Tab. 1. Table 2. shows the result of statistical test ($R^2$, $P$, and $MSE$) performed in the proposed models. The values of mentioned test are in the range of 0.7705-0.9908 for $R^2$, 0.2008-0.0156 for $P$, and 0.0105-0.0002 for $MSE$. According to the criteria of the highest $R^2$ and the lowest $MSE$ and $P$, the model of Wang and Singh are an appropriate model to represent the drying kinetic behavior of mendong. Figure 3. shows the comparison between the experimental data and the predicted data using mathematical equation for drying modeling. The prediction using the model showed $MR$ values banded along the straight line, which shows the appropriateness of these models in describing drying characteristic of mendong drying.
Table 3. Summary of the various FNN structure evaluated to yield the best $R^2$ and MSE

| Training Function | Transfer Function | Number of Neurons | $R^2$ Training | $R^2$ Validation | $R^2$ Test | MSE Training | MSE Validation | MSE Test | Epoch |
|------------------|-------------------|-------------------|----------------|------------------|-----------|--------------|----------------|----------|-------|
| Trainlm          | Tansig            | 10                | 0.9933         | 0.9947           | 0.9814    | 0.00114      | 0.00139        | 0.00120  | 23    |
|                  |                   | 20                | 0.9958         | 0.9876           | 0.9907    | 0.00105      | 0.00194        | 0.00200  | 26    |
|                  |                   | 30                | 0.9944         | 0.9946           | 0.9876    | 0.00120      | 0.00194        | 0.00200  | 25    |
|                  |                   | 40                | 0.9937         | 0.9921           | 0.9840    | 0.00104      | 0.00200        | 0.00223  | 15    |
|                  |                   | 50                | 0.9914         | 0.9947           | 0.9840    | 0.00114      | 0.00223        | 0.00220  | 14    |
| Logsig           |                   | 10                | 0.9916         | 0.9926           | 0.9904    | 0.00150      | 0.00179        | 0.00200  | 28    |
|                  |                   | 20                | 0.9999         | 0.9958           | 0.9929    | 0.00093      | 0.00194        | 0.00200  | 51    |
|                  |                   | 30                | 0.9937         | 0.9877           | 0.9921    | 0.00194      | 0.00284        | 0.00320  | 26    |
|                  |                   | 40                | 0.9923         | 0.9892           | 0.9859    | 0.00200      | 0.00284        | 0.00320  | 23    |
|                  |                   | 50                | 0.9951         | 0.9851           | 0.9880    | 0.00223      | 0.00284        | 0.00320  | 23    |
| Purelin          |                   | 10                | 0.9846         | 0.9850           | 0.9916    | 0.00303      | 0.00179        | 0.00200  | 7     |
|                  |                   | 20                | 0.9851         | 0.9904           | 0.9862    | 0.00179      | 0.00284        | 0.00320  | 11    |
|                  |                   | 30                | 0.9869         | 0.9815           | 0.9858    | 0.00284      | 0.00320        | 0.00440  | 11    |
|                  |                   | 40                | 0.9880         | 0.9864           | 0.9745    | 0.00231      | 0.00320        | 0.00440  | 10    |
|                  |                   | 50                | 0.9860         | 0.9918           | 0.9777    | 0.00187      | 0.00320        | 0.00440  | 9     |
| Traingdx         | Tansig            | 10                | 0.9889         | 0.9908           | 0.9928    | 0.00137      | 0.00187        | 0.00200  | 59    |
|                  |                   | 20                | 0.9906         | 0.9876           | 0.9911    | 0.00187      | 0.00284        | 0.00320  | 50    |
|                  |                   | 30                | 0.9921         | 0.9910           | 0.9898    | 0.00154      | 0.00284        | 0.00320  | 46    |
|                  |                   | 40                | 0.9713         | 0.9774           | 0.9783    | 0.00380      | 0.00284        | 0.00320  | 97    |
|                  |                   | 50                | 0.9904         | 0.9908           | 0.9865    | 0.00148      | 0.00320        | 0.00320  | 170   |
| Logsig           |                   | 10                | 0.9868         | 0.9886           | 0.9814    | 0.00265      | 0.00134        | 0.00200  | 212   |
|                  |                   | 20                | 0.9872         | 0.9923           | 0.9865    | 0.00134      | 0.00200        | 0.00200  | 210   |
|                  |                   | 30                | 0.9635         | 0.9064           | 0.9470    | 0.01351      | 0.00231        | 0.00320  | 105   |
|                  |                   | 40                | 0.9875         | 0.9872           | 0.9955    | 0.00231      | 0.00320        | 0.00320  | 175   |
|                  |                   | 50                | 0.9850         | 0.9762           | 0.9896    | 0.00481      | 0.00320        | 0.00481  | 182   |
| Purelin          |                   | 10                | 0.9871         | 0.9810           | 0.9866    | 0.00388      | 0.00233        | 0.00320  | 167   |
|                  |                   | 20                | 0.9847         | 0.9817           | 0.9919    | 0.00233      | 0.00233        | 0.00320  | 55    |
|                  |                   | 30                | 0.9855         | 0.9888           | 0.9849    | 0.00192      | 0.00233        | 0.00320  | 89    |
|                  |                   | 40                | 0.9842         | 0.9901           | 0.9930    | 0.00175      | 0.00233        | 0.00320  | 163   |
|                  |                   | 50                | 0.9851         | 0.9880           | 0.9819    | 0.00169      | 0.00233        | 0.00320  | 83    |

Table 3. summarizes a list of the best neural network topology structure, threshold function, and different applied algorithms in predicting MR for drying of mendong. As shown in the Tab. 3, most applied topologies and threshold functions have a proper training and validation errors. In fact, it could be asserted that neural network are powerful tools for modeling of drying of mendong in different condition which have accuracy and low cost and time. Among the different topologies presented in Tab. 3, the neural network with 3-20-1-1 structure, trainlm training function (Levenberg-Marquardt training algorithm), and logsig transfer function, has the lowest error and the highest coefficient of determination.
Figure 4. Training error curve

Figure 4. shows the training, validation, and testing stage for the best network. The network error (MSE) of this topology are 0.0009. This network convergent through 51 epoch. The regression analysis showed that $R^2$ for training, validation, and testing patterns was 0.9999, 0.9958, and 0.9929, respectively.

![Training error curve](image)

Figure 5. Comparison between the experimental data and the predicted values of the ANN model for prediction

The comparison of moisture ratio between the experimental result and the FNN modeled result presented in Fig. 5. A linear fitting (regression) is performs on the dependent parameters of drying. Comparison of Fig. 3 and Fig. 5 demonstrate that both mathematical equation and FNN models have good accuracy in modeling the process of drying mendong. But since the mean percent errors of empirical correlations for whole range of experiments and FNN models are compare, the correlation coefficient in Fig. 3 and Fig. 5 clearly show that the FNN model are more accurate than mathematical equation approach. Here FNN shows powerful tool in modeling drying kinetic for mendong.
4. Conclusion
From our experimental result, the drying times of the samples in microwave oven are reduce significantly as the power input of microwave oven increases. The mathematical equation are validates with experimental drying data and develops to determine the drying rate of mendong. The FNN structure with one hidden layer is determine considering different activation function and neuron numbers at hidden layer. According to analysis results, the FNN with back propagation appropriate in term of prediction drying rate. A comparative study is performs between mathematical equation model and FNN model. The $R^2$, $P$ and $MSE$ are used as evaluation criteria. Our result shows that the FNN model has a good agreement and better than mathematical equation approach. This means that the obtained FNN models provide a useful tools for analyzing drying rate and potentially applied to determine the optimal parameters during mendong drying.

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