

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 elephant yan (*Amorphophallus paeoniifolius*) [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 determine 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* \pm 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 \pm 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 \pm 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 bassis).

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 \pm 0.01 *g*. The moisture loss of samples during drying weighed and recorded within 2 *minute* \pm 2 *second* intervals. The temperature changes in the sample was also measured using a digital thermometer (Blue Gizmo) with accuracy \pm 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 \pm 5 *g* placed in two 1*L* beakers (Pyrex 1000) at an initial water temperature of 20 \pm 2°C. The beakers were placed in the center of the microwave oven. The microwave oven was turned on for 2 *minutes* \pm 2 *seconds*. Then the beakers were removed from the microwave oven. The final temperatures were measured and recorded. The power was calculated as follows:

$$P(W) = 70 \frac{(\Delta T_1 + \Delta T_2)}{2} \quad (1)$$

Where $P(W)$ was microwave oven power. ΔT_1 and ΔT_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 categorize 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]:

$$\frac{\partial M}{\partial t} = D_{eff} \frac{\partial^2 M}{\partial x^2} \quad (2)$$

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]:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (3)$$

Where M_t is the moisture content ($kg_{water} kg^{-1} dry\ material$) 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]:

$$MR = \frac{M_t}{M_0} \quad (4)$$

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.

Table 1. Standard models reported in the literature used for drying of agricultural products [10]

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:

$$MSE = \frac{\sum_{i=1}^N (MR_{pred,i} - MR_{exp,i})^2}{N - N_p} \quad (5)$$

$$P = \frac{1}{N} \sum_{i=1}^N \left| \frac{MR_{pred,i} - MR_{exp,i}}{MR_{exp,i}} \right| \quad (6)$$

$$R^2 = 1 - \frac{\sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^N (MR_{exp,i})^2} \quad (7)$$

Where $MR_{exp,i}$ stands for the experimental moisture ratio found in any measurement and $MR_{pre,i}$ 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.

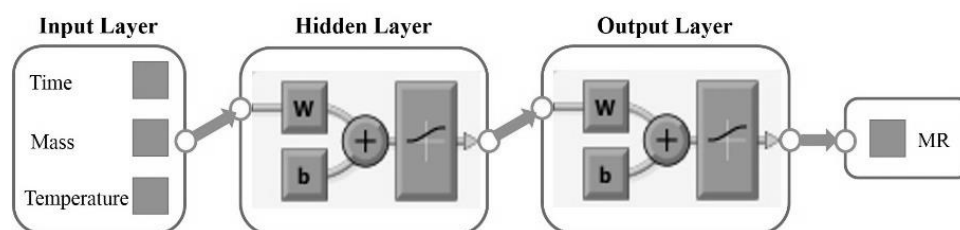


Figure 1. Configuration of feedforward neural network for predicting moisture ratio

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 3×279 and 1×279 , 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 3×223 , 3×28 , and 3×28 , 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

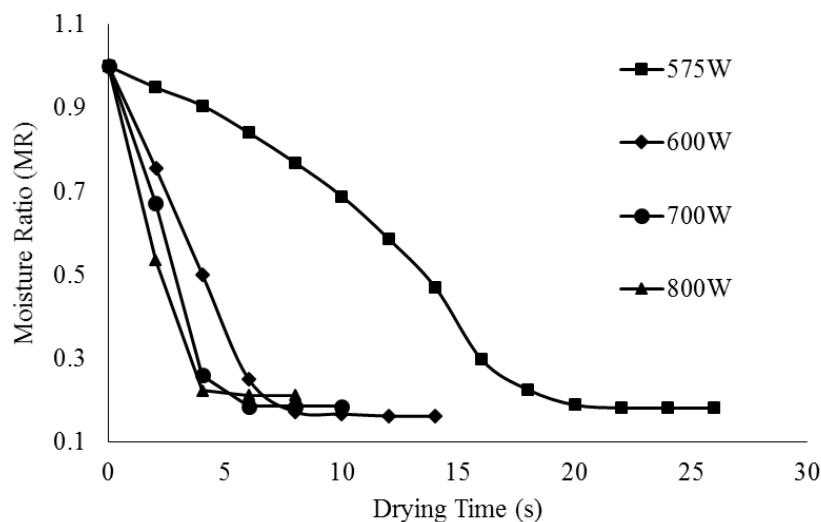
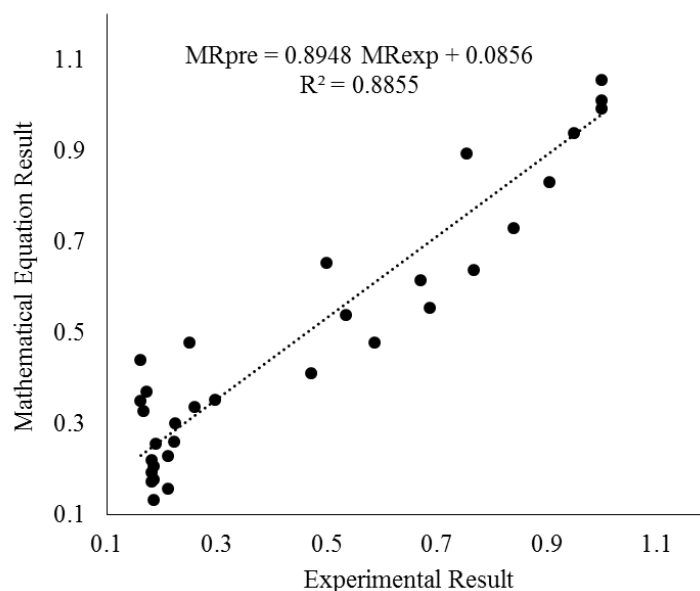


Figure 2. Various of moisture ratio with time for mendong sample under different microwave power

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			MSE	Epoch
			Training	Validation	Test		
Trainlm	Tansig	10	0.9933	0.9947	0.9814	0.00114	23
		20	0.9958	0.9876	0.9828	0.00139	26
		30	0.9944	0.9946	0.9907	0.00105	25
		40	0.9937	0.9921	0.9876	0.00120	13
		50	0.9914	0.9947	0.9840	0.00104	15
	Logsig	10	0.9916	0.9926	0.9904	0.00150	28
		20	0.9999	0.9958	0.9929	0.00093	51
		30	0.9937	0.9877	0.9921	0.00194	26
		40	0.9923	0.9892	0.9859	0.00200	23
		50	0.9951	0.9851	0.9880	0.00223	23
	Purelin	10	0.9846	0.9850	0.9916	0.00303	7
		20	0.9851	0.9904	0.9862	0.00179	11
		30	0.9869	0.9815	0.9858	0.00284	11
		40	0.9880	0.9864	0.9745	0.00231	10
		50	0.9860	0.9918	0.9777	0.00187	9
Traingdx	Tansig	10	0.9889	0.9908	0.9928	0.00137	59
		20	0.9906	0.9876	0.9911	0.00187	50
		30	0.9921	0.9910	0.9898	0.00154	46
		40	0.9713	0.9774	0.9783	0.00380	97
		50	0.9904	0.9908	0.9865	0.00148	170
	Logsig	10	0.9868	0.9886	0.9814	0.00265	212
		20	0.9872	0.9923	0.9865	0.00134	210
		30	0.9635	0.9064	0.9470	0.01351	105
		40	0.9875	0.9872	0.9955	0.00231	175
		50	0.9850	0.9762	0.9896	0.00481	182
	Purelin	10	0.9871	0.9810	0.9866	0.00388	167
		20	0.9847	0.9817	0.9919	0.00233	55
		30	0.9855	0.9888	0.9849	0.00192	89
		40	0.9842	0.9901	0.9903	0.00175	163
		50	0.9851	0.9880	0.9819	0.00169	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.

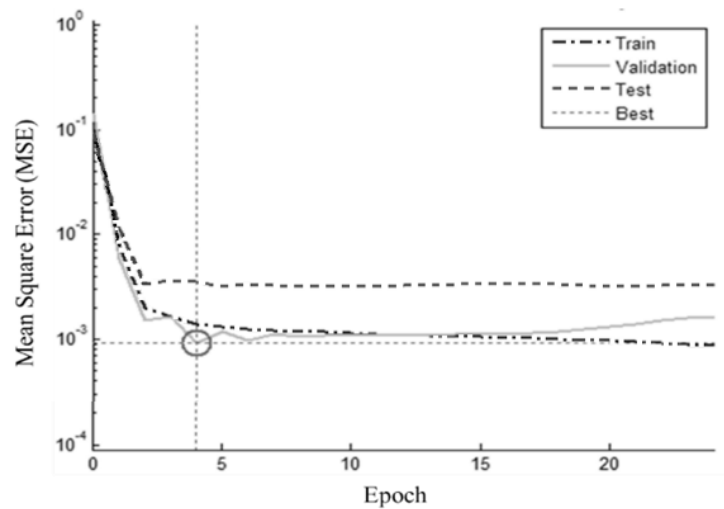


Figure 4. Training error curve

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.

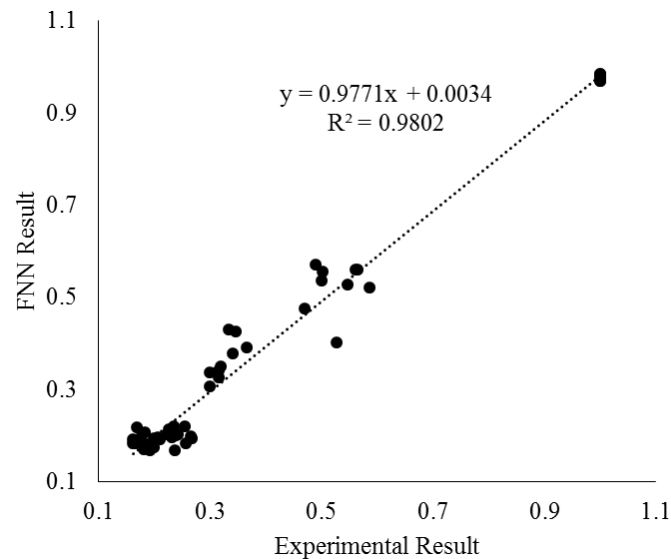


Figure 5. Comparison between the experimental data and the predicted values of the ANN model for prediction

The comparison of moisture ratio between the experimental result and the FNN modeled result presented in Fig. 5. A linear fitting (regression) is performed 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 compared, the correlation coefficient in Fig. 3 and Fig. 5 clearly show that the FNN model is more accurate than the mathematical equation approach. Here FNN shows a powerful tool in modeling drying kinetics 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.

Acknowledgement

The authors are grateful to head of department of Master Physic in Teaching, ITB for providing research facility.

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