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The Application of Mathematical Model Drying of Galangal (*Alpiniagalanga* L.) Using Hybrid Dryer Equipment with Rotary Type of Rack

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Abstract. This research aims to apply mathematical modeling, optimizing the performance and compare mathematical models with actual measurements on a tool Hybrid Solar Dryer Rack Type Spinning. The method used in this study is an experimental method that is done in the field .This material used in this study is a piece of galangal with a thickness of 0.5 cm. Parameters that used in this observation is the intensity of sunlight, the temperature of drying chamber, the temperature of the material in drying chamber, relative humidity in drying chamber, and the moisture content of materials. The results showed that the coefficient of determination (R^2) MR Page in dryeris MR = exp (-0.0043 * t0,9046), X^2 and RMSE value when approaching a value of zero indicates that the model drying closer observation results. Based on the suitability value, the Page model is the best model to represent the Mathematical Model Drying Galangal(*Alpiniagalanga* L.)Hybrid Dryer Rotary Type of Rack.

INTRODUCTION

One of the efforts to handle galangal after harvest is drying. Drying is one of the post-harvest handling stages which is quite critical in determining quality. During this time, drying that can be done in Indonesia is traditional drying by drying or smoking. Drying by drying depends on the sunny weather conditions so that it is easily damaged, moldy and can be damaged by insects. While fumigation takes longer and is at risk of fire. The drying method needed to dry the galangal is using an artificial dryer or drying machine. Artificial drying is a drying method which in the drying operation uses the aid of a dryer. This method aims to overcome the shortcomings of natural drying methods, besides that drying using a dryer can be more continuous and more controlled. One of the artificial dryer is greenhouse dryer. Research on the utilization of the greenhouse effect dryer for agriculture product has been done[1, 2, 3, 4].

The drying system recognizes a simulation model that is used to study and analyze the characteristics of the dried material. Simulation is a method by which system or process performance can be predicted using a mathematical model. The simulation studies the drying process so that it will basically depend on the analysis of changes in heat and mass and humidity in the material. The rate of change occurs gradually and is influenced by the structure of the material, the drying process carried out and the drying media. The modeling principle, to explain how the system works during the drying process, is based on various mathematical equations. The solution of this equation must allow the calculation of predetermined parameters that affect the condition of the material during the drying process. Therefore, the use of mathematical models is an important tool for simulating the performance of a drying system [5].

Mathematical modeling of the drying process in a variety of operating conditions is very important to get a model that can be used for controlling purposes during the commercial scale drying process and can also be used to improve overall improvements to the quality of the final product. Several models are often used to study the effect of variables used in the process, predict the kinetics of product drying and optimize operating parameters and conditions[6]. In addition, the simulation of the drying process is also important to carry out a drying process with a

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greater amount of material and is also used to design or repair dryers that are more effective and efficient for certain commodities.

The purpose of this study to apply a mathematical model in optimizing the performance of the Rotating Rack Solar Powered Hybrid Dryer and compare the mathematical models with actual measurements on the Hybrid Solar Dryer Rotating Rack Type.

MATERIALS AND METHODS

The material used in this study is galangal with a thickness of 0.5 cm. The equipment used in this research are hybrid rotating rack dryer, thermodigital, T-type thermocouple (C-C), moisture analyzer, wet ball and dry ball thermometer, stop watch, Kanomax 60011 model anemometer, lux meter, analytical balance. The method used in this study is an experimental method carried out in the field.

$$MR = \frac{M_t - M_e}{M_o - M_e} \tag{1}$$

MR = moisture rasio
Mt = water content at time t
Mo = initial moisture content (%)
Me = water content at equilibrium (%db)

$$Ka_{bb} = \frac{Wa}{Wt} \text{ x } 100\% = \frac{Wt - Wk}{Wt} \text{ x } 100\% \tag{2}$$

$$Ka_{bk} = \frac{Wa}{Wk} \text{ x } 100\% = \frac{Wt - Wk}{Wt - Wa} \text{ x } 100(3) \tag{3}$$

Ka_{bb} = water content (% wb)
Ka_{bk} = water content (% db)
Wa = mass of water in the material (g)
Wk = dried weight (g)
Wt = total weight (g)

Mathematical models used in this experiment are Newton, Page and Henderson-Pabis.

TABLE1. Mathematical Equation

Drying Model	Linier Form	References
Henderson-Pabis	ln MR = ln a – kt	[7]
Page	ln (–ln MR) = ln k + (n) ln (t)	[8]
Newton	ln MR =–kt	[[6]

Table 1 represents the change in the model's exponential form to its linear form, where the MR value of each model if linearized will be Ln MR and the form of exp will change to Ln. The completion of the mathematical model is done using Microsoft Excel. After finding the value of the Moisture Ratio (MR) observed in the drying process, then linear regression (in Ln right) to form Ln MR. The Ln MR value is then plotted into a graph against the drying time. To find the constant value of Newton's model, it is done by issuing an equation of the values of y and R^2 on the graph. The steps include addtrend line, then choose the set of intercepts and display the equation y and the value R^2 on the graph, after which the value of y = -kx will emerge, where k is the constant value on Newton's model, while t is the drying time.

In the Henderson Pabis model [7], the MR value in Ln is plotted into a graph with respect to time, then a trendline is added and displays the equation y and R^2 to find the values of k and a. After finding the value of each model constant, then the value of the constant is entered into its exponential form. The results of data analysis are made in the form of graphs and tables. Observation data obtained were then compared with the alleged data generated through mathematical equations. The validity of the mathematical equation model obtained will be even higher if the value of the Coefficient of Determination (R^2) between the prediction data and the observation data approaches one. Regression analysis is used to determine the closeness of the relationship between observational and alleged data.

To determine the suitability of the drying model with the observational data used the formula χ2 (chi square) and RMSE (root mean square error) as follows:

$$\chi 2 = \frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2}{N-Z}. \quad (4)$$

χ2	= *Chi square*
MRexp,i	= *Moisture Ratio* experiment
Z	= 1
N	= numbers of data

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2}{N}} \quad (5)$$

RMSE	= *Root Mean Square Error*
MRexp,i	= *Moisture Ratio* experiment
MRpre,i	= *Moisture Ratio* prediction (MR model)

Experimental Procedure

The research procedures in this study are as follows:

1. Put the solar hybrid dryer on an open field that is not exposed to shade all day long stretching the device east to west so that the path of the sun moves on the dryer from one side to the other.
2. Prepared galangal material that has been cleaned and sliced 0.5 cm.
3. Put galangal on each rack with 1 layer evenly with 678gram galangal weight / pan on each shelf and put the pan in the middle of the rack as a sample weight measurement material.
4. Observation on the weight of the material to determine the water content taken from the sample on the baking sheet with measurement intervals every 30 minutes.
5. Put the thermometer in the drying chamber, biomass furnace, heat exchanger and exhaust fan.
6. Temperature measurement in the drying chamber rack laid out at several points, namely: rack, chimney, biomass furnace, heat exchanger and exhaust fan. Temperature measured using thermodigital with measurement interval of 30 minutes.
7. The intensity of sunlight is measured using a lux meter. Measurement of light intensity is done in an open environment that is exposed to sunlight, measurements during the day with a measurement interval of 30 minutes.

RESULTS AND DISCUSSION

Water Content

The moisture content of the material indicates the amount of water content of the weight of the material. One of the factors that influence the drying process is the water content. The drying aims to reduce the moisture content of materials to inhibit the development of spoilage organisms. The water content of an ingredient affects the amount of water evaporated and the length of the drying process.

Figure 1 shows the relationship between decreased galangal water content and drying time. Galangal water content continues to decrease from the first day of the drying process to equilibrium galangal water content. The initial water content of galangal was 83.33% wet basis and continued to decrease until it reached the equilibrium water level at 10.41% wet basis. The amount of galangal water content that is lost during the drying process is influenced by the drying chamber temperature, humidity of the drying chamber air, the initial moisture content of the galangal itself and the air velocity of the dryer.

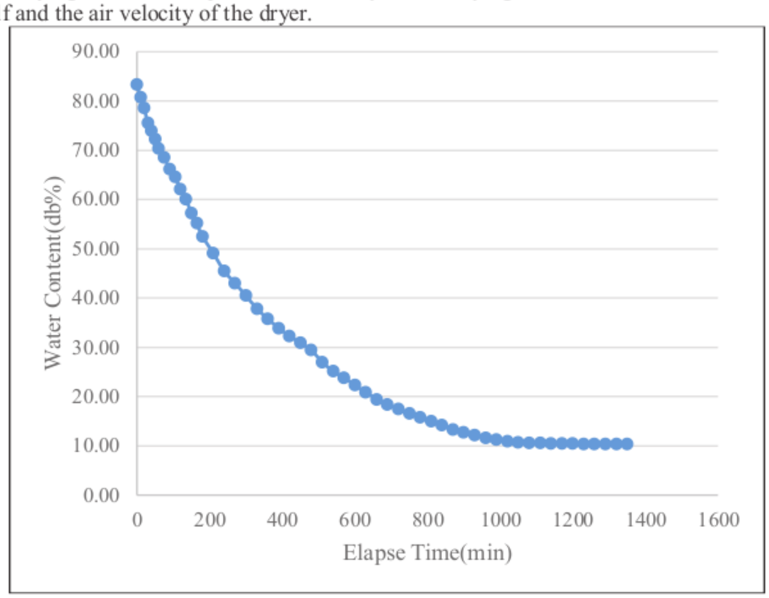

FIGURE 1.The graph of the relationship between the drying time and the water content

TABLE 2. The Constant Value and R^2 of Each Drying Model

Model Newton		**Model Henderson Pabis**			**Model Page**		
k	R^2	k	a	R^2	k	N	R^2
0.0022	0.976	0.002	1.1424	0.9738	0.0043	0.9046	0.997

Based on Table 2, the Page model has a higher R^2 value and is approaching one which is 0.997 with the k value is 0.0043. Where, the value of k is a constant rate of drying which is a combination of the properties of the displacement in drying such as effective diffusivity, water content, thermal conductivity and mass coefficient[9]. R^2 values that are close to 1 indicate that the Page model has a greater conformity compared to the Newton model and the Henderson-Pabis model of galangal drying with a rotating rack type hybrid dryer. After the constant values of each model are found, then the value of t (drying time) is entered into the equation of each model and the results of the MR predictions of each model with the MR observations.

Conformity of the Drying Model

The constant values that have been entered into each equation in the model's exponential form (Table 1) are then calculated to find the MR values of the Newton model, the Henderson-Pabis model and the Page model. After obtaining the results of the calculation of MR prediction using the three models from the beginning of drying to the end of drying then comparing the decrease in MR prediction with MR observation of the drying time.

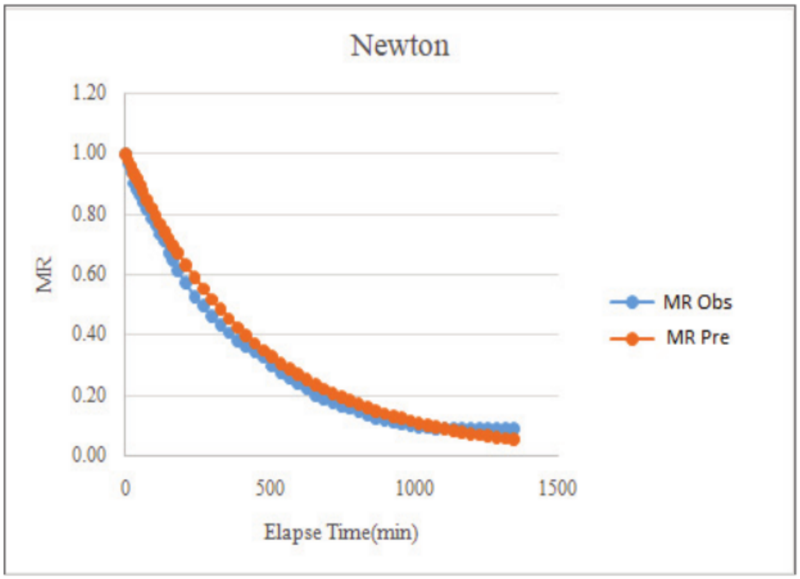

FIGURE 2. TheComparison Graph of MR Observation chart with MR Prediction of Newton model

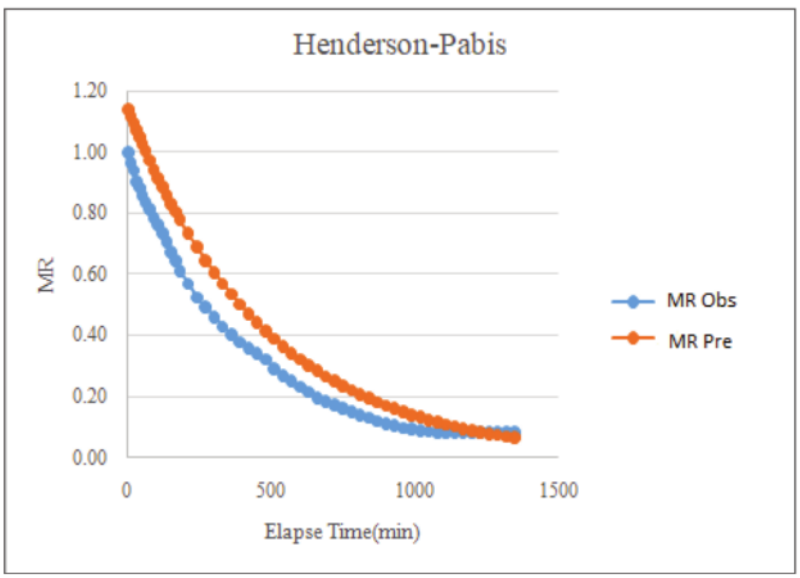

FIGURE 3.TheComparison Graph of MR Observation chart with MR Prediction of Henderson-Pabis model

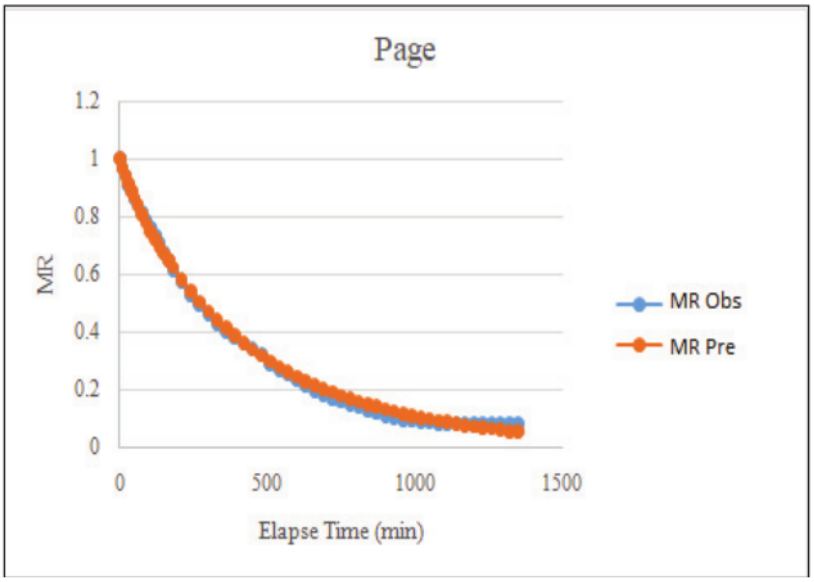

FIGURE 4.TheComparison Graph of MR Observation chart with MR Prediction of Page model

FIGURE 3 – 4 showed the comparison of the decreasing in MR observation with the predicted MR Newton model, the Henderson-Pabis model, and the Page model to the drying time. Where Newton, Henderson-Pabis, and Page models are used to predict the decrease in MR of the galangal drying of the three have a tendency that is the same as the value of Observation MR. In Figure 3it is clear that the Henderson-Pabis model has a higher MR value than the Observation MR. Figure 4, the prediction value of MR of Page model has a decrease in MR value which is closer to MR observation. It is also appropriate based on the R^2 value of 0.997 Page model which is the closest to the ratio of water content observed. In addition to using the R^2 value, to ensure the validity level of the model also used the value of Chi Square and Root Mean Square Error, which is basically the smallest square of the difference between the value of the observation model and the observation value of the model. Below is a table showing the MR equations of each model and their validation values.

TABLE 3. Each Model Equation and Validation Value χ^2 and RMSE.

Model	Equation	Validation Model	
		χ2	**RMSE**
Newton	MR= exp(-0.0022*t)	2.15×10^{-5}	0.0337
Henderson-Pabis	MR= 1.1424*exp(-0.002*t)	0.000232	0.1109
Page	MR= exp(-0.0043*$t^{0.9046}$)	3,15 $\times 10^{-6}$	0.0129

The MR value for Page model can be found by the equation MR = exp (-0.0043*$t^{0.9046}$) with a chi square value (χ^2) of 3.15×10^{-6} and root mean square error (RMSE) of 0.0129. The MR value for Newton's model can be found by the equation Mr = exp (-0.0022 * t) with a chi square value (χ^2) of 2.15×10^{-5} and root mean square error (RMSE) of 0.0337. Whereas the Henderson-Pabis model can be calculated through the equation MR = 1.1424 * exp (-0.002 * t), with a chi square value (χ^2) of 0.000232 and root mean square error (RMSE) of 0.1109. Where, the value of t is the drying time. Chi square (χ^2) and root mean square error (RMSE) values when approaching 0 indicate that the model is most suitable for describing the value of MR observation on the dryer. Therefore Page model is the best model to present the mathematical model of galangal drying on a rotating rack type solar hybrid dryer with chi square value (χ^2) and root mean square error (RMSE) of 3.15 x10^{-6} and 0.0129.

CONCLUSION

The moisture content of galangal was reduced within 2 days. The Page model is the most appropriate and close mathematical model to describe galangal drying in a rotating rack type solar hybrid dryer compare with Henderson Pabis and Newton.

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