Study of mathematics modeling on ginger geometric changes during drying using image analysis

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Abstract. Many studies have examined the drying process, but only a few studies have examined shrinkage as one of the parameters that affect drying. Depreciation of agricultural products could have an impact on damage and reduce quality. This study aimed to examine the shrinkage pattern of product size during drying using the mathematical model approach regression. The method used was experimental with sliced ginger as material. The equipment used was a rack-type hybrid dryer and a set of image capture devices. This study indicates that to dry the sliced ginger from 95.65% to 9.49% moisture content required approximately 8 hours. The results of image processing showed shrinkage that occurs in sliced ginger was 52.49%. The most accurate mathematical model describing the prediction of sliced ginger shrinkage during drying was the 2nd order polynomial regression model with the equation of \[ y = -131.3x^2 - 1804.4x + 41941.6 \] and an \( R^2 \) value of 0.99.

1. Introduction
Ginger (Zingiber officinale) is a type of spice that is very popular as a medicinal plant, a cooking spices, and consumed directly in drinks. Ginger has the advantage of having bioactive compounds such as phenolic compounds (shogaol and gingerol) and essential oils [1]. From January to May 2018, exports of 1,400 tons of ginger increased to 1,543 tons (10.2% increment) from January to May 2019. Ginger is exported in the form of fresh and processed ginger, dried ginger, and essential oils. Some countries that become export destinations are Japan, Hong Kong, Korea, Taiwan, and China [2].

Post-harvest handling technology on crop commodities is required to maintain the quality of harvested commodities. One way to handle post-harvest ginger is drying. The purpose of drying is to reduce the water content in the product [3]. The drying process is essential to obtain dried ginger with less water content, long durability in the storage process, and high resistance from mold growth. Numerous previous research has been carried out on drying crops, including Yilmaz et al. [4] that study the effect of drying on the transfer of water content and quality of pomegranate skin; and Supakarn et al. [5] about the equilibrium of water content during the thin layer drying of fungus. Furthermore, Amjad et al. [6] investigated Hyperspectral Imaging to determine the water content of sliced potato and chromaticity during the hot air drying process; and Sukmawaty et al. [7] about the application of mathematical models to galangal drying.
Occasionally, the dried commodities will appear in a shrinkage size. According to Manalu 
& Tambunan [8], dried commodities will experience cracks and shrinkage of materials. This condition 
often occurs when the shrinkage is not uniform, and the drying rate is too high. Previous studies have 
examined the drying process in general, but few have examined the shrinkage factor as one of the 
parameters affected by drying. Therefore, this research examines the dried ginger size's shrinkage 
pattern during drying with the mathematical regression model approach.

2. Experimental Method
This research was conducted by using experimental methods. Ginger was dried using a hybrid dryer 
(solar biomass), and the results were analyzed at the Bioprocess Laboratory of the Faculty of Food and 
Agroindustrial Technology, University of Mataram. The data obtained then further analyzed using a 
mathematical model with R program software.

2.1. Materials
The material used in this study was fresh ginger (Zingiber officinale). Ginger used as a sample was 
sliced 1 mm thick and weighed approximately 3-5 g.

2.2. Apparatus
Equipment used in this research were wet and dry ball thermometers, HTC-2 thermo-digital brands, 
Hybrid solar and biomass dryer (figure 1), OEM GM816 anemometer, DSC 500 gr digital scales, Philips 
TL 5-watt, Canon PowerShot SX280HS 12,1 MP Digital camera (CMOS sensor 3 inch TFT LCD Screen).

Figure 1. Hybrid solar and biomass dryer.

2.3. Observed parameters
2.3.1. Water content
The measurement of water content was conducted using the Gravimetry method. First, the sample was 
placed on a dried-cup and then weighed using a digital scale. The sample and the cup were then put into 
the oven and dried at 105°C for 24 hours. After dried, the cup and ginger then cooled and weighed again. 
The sample's weight was obtained by reducing the total weight (the cup and ginger) by the weight of the 
cup. The weighing was applied every 1 hour until a constant weight was obtained. Equation 1 shows 
the formula for calculated moisture content on a wet base.

\[
K_{wb} = \frac{W_a}{W_t} \times 100\% = \frac{W_t - W_k}{W_t} \times 100\%
\] (1)
Where:
\( K_{\text{bb}} \) = moisture content (\%)
\( W_a \) = mass of water (g)
\( W_k \) = mass of material (g)

2.3.2. \( W_t = \text{total mass (g)} \)

**Geometric size**

The measurement of ginger geometric size was conducted with a digital image approach using a camera. Image capture was applied to one side of the object with the largest cross-sectional area using a black background; the digital image recording scheme is illustrated in Figure 2 [9].

![Schematic diagram of digital image capturing and processing.](image)

Based on Figure 2, the ginger sample was placed into a 30 mm x 45 mm box. The inner part of the box was coated in black cloth. At 200 mm distance from the base, a digital camera and four fluorescent lamps (1800 lux) were placed at the top of the box to obtain the best luminous. The object's captured image was then saved in a file with the bitmap format (.bmp) in the dimension of 400 x 300 pixel using *Paint Software*. The image quality improvement was conducted by increasing brightness or reducing the noise in the digital image programs. The method to reduce noise was by removing spots on the object to smoothing the image by maintaining the object's contrast (to prevent blurry image). The sliced ginger area was calculated from the binary image generated on the object and background removal phase. The number of pixels referred to the sliced ginger after the thresholding operation. Simultaneously, the ginger shape was studied through the roundness index using an algorithmic approach shown by equation 2[10].

\[
R = \frac{4 \pi \times \text{area}}{\text{perimeter}^2} \quad (2)
\]

2.4. **Determination of mathematical approach of shrinkage**

The regression model is one type of mathematical equation that could predict the value of independent variables from those derived from independent variables [11]. The form of the relationship between the independent variable (X) with the dependent variable (Y) can be in the form of the first-degree polynomial (linear), second-degree polynomial (quadratic), third-degree, or polynomial (cubic).

Moreover, it could also be in other forms, such as exponential, logarithmic, or sigmoid. A strict separation is necessary to determine a model between the independent variable (X) and the dependent variable (Y). The relationship between variable X and variable Y can be written in the form of equation
1. Whereas the value of a dan b calculated using equation 4, and correlation coefficient (R) calculated using equation 5.

\[ Y = a + bX \]  

\[ b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \quad \text{and} \quad a = \frac{\sum y - b.(\sum x)}{n} \]  

\[ R = \frac{n \sum XY - \sum X \sum Y}{\sqrt{\left| n \sum X^2 - (\sum X)^2 \right| \left| n \sum Y^2 - (\sum Y)^2 \right|}} \]  

The value of R is the degree of relationship between X and Y, While the coefficient of determination (R^2) is shown in equation 6.

\[ R^2 = RR \]  

Like linear regression, polynomial regression is a regression in which the function is quadratic [12]. This regression model is used if the data used are not linear. The least-squares method can be extended again to match the measurement data on a polynomial order. In general, polynomials of N order could be written as in equation 7.

\[ f(x) = a_0 + a_1x + a_2x^2 + ... a_nx^n \]  

2.5. Validation and verification of model

In choosing the mathematical model to be used, it can be based on the validation and verification test results. A validation test is a process of determining whether the conceptual model accurately reflects the actual system. In contrast, the verification test is used to calculate the error of the method to be used. In this study, the Mean Absolute Percentage Error (MAPE) method was chosen. One of the advantages of MAPE is that it could calculate the percentage of error forecasting results against the actual conditions for a specified period. The MAPE formula is shown in equation 8.

\[ \text{MAPE} = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{Y_i - \hat{Y}_i}{Y_i} \right| \]  

2.6. Research flow diagram

The research process is carried out in three stages, i.e., the drying process, taking pictures with image analysis, and determining the mathematical model. The mathematical model approach uses the regression equation approach. If the MAPE value is still high, a polynomial regression approach will be performed. Figure 3 shows a flowchart of the research process carried out.
3. Results and Discussion

3.1. Physical properties and actual geometry

Material shrinkage is observed from the physical and geometrical characteristics of the dried ginger. During the drying process, ginger undergoes mass and geometry shrinkage. Table 1 shows the shrinkage of ginger mass during drying.

During the drying process, the mass of material experiences shrinkage. This condition is due to water released by the material through the evaporation process. Evaporation could occur because there is a difference in the air's moisture content with the moisture content in the drying chamber. Table 1 shows the percentage decrease in the mass of material during the drying process. At the beginning of drying, the percentage decrease in the material's mass is low because the temperature in the drying chamber remains low. After 3rd hour, the percentage of significant mass reduction starts from 13.95%, and as the temperature rises in the drying chamber, the percentage of mass shrinkage will increase. The most significant decrease in material mass percentage occurred at the 8th hour, around 33.64%. This result is consistent with the statement of Dwika et al. [13], which implied that the material would dry faster as

![Research flow diagram](image-url)
the temperature of the heater goes into the drying chamber is higher since it encourages faster removal of water that enhances shorter drying time.

Table 1. Mass of material during drying.

| Period | Average mass (g) | Percentage of mass shrinkage (%) |
|--------|-----------------|---------------------------------|
| 1      | 18.67           |                                 |
| 2      | 18.12           | 2.91                            |
| 3      | 17.14           | 5.44                            |
| 4      | 14.75           | 13.95                           |
| 5      | 11.81           | 19.91                           |
| 6      | 7.93            | 32.85                           |
| 7      | 5.78            | 27.15                           |
| 8      | 3.92            | 32.08                           |
| 9      | 2.60            | 33.64                           |

Figure 4. The relation between moisture content and drying time.

Figure 4 shows a decrease in water content from 95.65% to 9.49% after 8 hours of drying at 45°C. This value is similar to the previous researcher that obtained final moisture content of less than 10% by applying various drying methods at various temperatures of 50, 55, 60 and 65°C [14]. This decrease in water content indicates water evaporation due to the difference in water vapor content between the air and the dried material. The higher the drying temperature, the faster the time needed to dry the ingredients. A rapid decrease in moisture content was due to the massive heat produced from solar and biomass combined as the heat source on the hybrid dryer.

The water content decrease during drying caused the product to experience physical changes in shape, weight, and volume. Consumers usually prefer a uniform product of shape, weight, and volume, besides considering the product's damage or defects. Knowledge of the characteristics of the product's physical properties is necessary to prevent minimum damage using a physical, mechanical, and thermic approach [15].
3.2. Sliced ginger geometry during drying

Shrinkage patterns on sliced ginger products could be seen using digital images. Sampling was applied by using a camera and then processed using the imaging program. During the drying process, there is an increase in temperature in the drying chamber; the room temperature higher than the ambient temperature forced the sliced ginger sample's water content released through the evaporation process. This condition resulted in a smaller surface area of the sample.

The created digital images had successfully shown separate objects and backgrounds (Table 2). White objects were samples of sliced ginger, and black objects are backgrounds. The recorded objects have been through image processing improvement to reduce noise. This image processing process uses Visual Basic language with menus to read the image's RGB, HIS, and object surface area in pixels. The results obtained in this study indicated a decrease in surface area from 1 to 8 hours. At the beginning of the drying, the cross-sectional area changes only around 7.30%, but starting at 4 hours, the percentage of surface area reduction ranges from 10-15%. The small percentage of decrease in surface area in the first hour was due to the temperature in the drying chamber remained low. After 4 hours, the room temperature increased, which enhanced faster water release from the material. The release of water from the material caused change in dimensions, shown by the sliced ginger samples were getting smaller and wrinkled.

3.3. Linear regression model of ginger shrinkage during drying

The sliced area that is shrinking could be seen in Figure 4, representing the relationship between the surface area (pixel) to time. The surface area of the sliced ginger sample was decreased with the decreasing water content.
Figure 5. The simple linear regression model of ginger shrinkage.

The model developed in this experiment used average values from samples 1 and 2, shown in figure 5. Figure 5 shows that the drying of the sliced ginger for 8 hours caused a reduction in the surface area from 40100.5 pixels to 19049 pixels (reduced by 52.49%). The linear regression model produced from the relationship of area to time \( (y = 43911 - 2865x) \) shows the coefficient of determination \( (R^2) = 0.98 \). The coefficient of determination \( (R \text{ Square}) \) is useful for predicting and observing how much the X variable's contribution (affecting factors) simultaneously to the Y variable. The value of the coefficient of determination in Figure 4 implies that time \((X)\) affects the area \((Y)\) variable of 0.98 (98%). The constant \((a)\) value is 43911, indicating that at the initial period of 0 (zero), the area is 43911 pixels. The regression coefficient of -2865 means that the area has a negative relationship with time, which indicates that each reduction of 1 unit of time will affect the reduction of the sliced ginger area by 2865 pixels.

3.4. Second-order polynomial regression model of ginger shrinkage during drying

Figure 5 shows the relationship between area (pixel) to time. The surface area of the ginger sliced sample decreases with decreasing water content. The curved line shown in Figure 5 is a line derived from the 2nd order polynomial \( (y = -131.3x^2 - 1804.4x + 41941.6) \).

Figure 6. The 2nd order polynomial regression model of ginger shrinkage.

The 2nd order polynomial regression equation in Figure 6 shows the coefficient of determination \( (R^2) = 0.99 \). This value implies that time \((X)\) affects the variable area \((Y)\) of 0.99 (99%). Furthermore, from figure 6, it could be seen that the determination coefficient of the 2nd order polynomial regression equation is higher than the determination coefficient of the simple linear regression equation. This result
indicates that the 2nd order polynomial regression model provides a more accurate prediction of the area of the sliced ginger during the drying process.

3.5 Model validation and verification
Validation is a value that reflects the accuracy of the mathematical's conceptual model that has been built based on the existing system that is compiled on the running system. A model is said to be valid by mathematically test the truth, logically test the consistency and the similarity between the model and the real situation. From the two compiled models, R² values of more than 90% were obtained, which means that the designed model was valid.

Table 3. Verification of sliced ginger drying model.

| Period (hour) | Surface area (pixel) | Error (%) |
|---------------|----------------------|-----------|
|               | Sample 3 Polynomial  | Linear Polynomial | Linear |
| 1             | 36721                | 38719.49  | 39634.31 | 5.44 | 7.93 |
| 2             | 33359                | 36638.73  | 36769.42 | 9.83 | 10.22 |
| 3             | 31925                | 34296.6   | 33904.54 | 7.43 | 6.20 |
| 4             | 30871                | 31693.09  | 31039.65 | 2.66 | 0.55 |
| 5             | 26599                | 28828.21  | 28174.77 | 8.38 | 5.92 |
| 6             | 24724                | 25701.95  | 25309.88 | 3.96 | 2.37 |
| 7             | 21076                | 22314.31  | 22445.00 | 5.88 | 6.50 |
| 8             | 17724                | 18665.29  | 19580.11 | 5.31 | 10.47 |
| Average error | 6.11                 | 6.27      |

Table 3 shows the results of the model verification using the Mean Absolute Percentage Error (MAPE). The data used for verification were the actual data of other samples (sample 3) that were not used to build the model (sample 1 and sample 2). It is essential to notice that the data used in the verification phase should differ from the data used to develop the model. The percentage of error (MAPE) in the simple linear regression model was 6.27%, while the percentage of error (MAPE) in the 2nd order polynomial model was 6.11%. A model is determined as having a good performance if the MAPE value is between 0-10% and has less good performance if the MAPE value is 10%-20% [16]. Therefore, it could be concluded that the smaller the percentage of errors, the more accurate is the determined model.

4. Conclusions
The best model that describes the prediction of decreasing area of the sliced ginger during drying was the 2nd order polynomial regression model. This model showed a higher R square value of 0.99 than the simple linear regression model. From the calculation of the Mean Absolute Percentage Error (MAPE), the 2nd order polynomial regression model has a smaller error value (6.11%) than the simple linear regression model (6.27%).
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