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Moisture Diffusivity and Activation Energy on Breadfruit (*Artocarpus Altilis*) Drying

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Abstract:- The diffusivity coefficient can be determined from the dimensional graph of the water content ratio versus time and the water absorption rate using the second law of Fick's diffusion equation. This study uses a heat and mass transfer model based on experimental data's Fick diffusion differential equation. It is desired that these equations can determine the governance of the equation model and the heat and mass transfer transport model and can describe the physical phenomena that occur in the drying process. This study aimed to determine the coefficient of moisture diffusivity and activation energy of drying breadfruit with and without blanching treatment. The results showed that the effective moisture diffusivity value obtained for breadfruit drying was in the highest range of 1.29823^{-11} m^2/s, and the lowest was 6.49114^{-12}m^2/s. The value of this diffusion coefficient was still in the range of the effective diffusivity of food ingredients, which is between 10^{-13}-10^{-6} m^2/s (Zogzas & Maroulis, 2007); meanwhile, the activation energy range was between 58 - 70 kJ/mol. This activation energy value was still within the range of activation energy values for agricultural products, i.e., 12 - 110 kJ/mol (Aghbashlo et al., 2008). The correlation of moisture diffusivity with material temperature based on the activation energy value of breadfruit was in the highest range of 69,661 kJ/mol, and the lowest was 58,509 kJ/mol. This activation energy has an inverse relationship with water content, increasing the bond strength between water and material when the water content decreases (Heldman & Lund, 2006).

***Keywords:-** Activation Energy, Blanching Breadfruit (Artocarpus Altilis), Moisture Diffusivity.*

I. INTRODUCTION

Breadfruit or Artocarpus altilis (Park) Fosberg is a food that grows in almost all tropical countries and the Pacific islands that can be consumed as fruit or vegetables. Breadfruit is a versatile plant with economic value because it produces fruit with a high nutritional content of 27.82% carbohydrates and 75% moisture percentage (Correa et al., 2017). As a potential plant, breadfruit can be developed as a commodity-producing local food ingredient because breadfruit can be processed into various food menus; thus, it can support food security temporarily promoted by the government through local food diversification programs.

Breadfruit can be processed into several products, one of which is breadfruit flour. Processing breadfruit into breadfruit flour is not only able to increase its economic value but also can increase the consumption period of food products from breadfruit. However, this fruit product will also have the disadvantage of damage caused by oxidation, causing brown spots after peeling. These factors can affect the production process of breadfruit flour.

One effective way to maintain the quality of breadfruit flour products is to carry out a drying procedure. The drying method is very important and needed in food processing. An appropriate drying technology can determine the value of drying kinetics along with the properties and parameters that characterize the product drying process that can guarantee the conservation of a product.

Please note that almost all foodstuffs contain very high water content, which will be reduced through the dehydration process either partially or completely. Food drying involves heat and mass transfer processes both internally and externally. The importance of drying resistance varies significantly in the dehydration process for each type of food to be measured through the determination of the equation model. Therefore, in determining the governance of the equation model, the heat and mass transfer transport model will describe the physical phenomena that occur in the drying process. The main interaction processes that affect the external environment during the drying process are stated by boundary conditions. Therefore, various food thermal treatment processes can be modeled using the same equations but varying at boundary conditions (e.g., frying or hot air drying). Thus, it is very important to understand the condition or basic knowledge of food ingredients that can be predicted based on the model used accurately.

One of the main approaches that can be used to determine the breadfruit drying model is to determine the moisture diffusivity by measuring the water content experimentally and calculating using the Fick model that follows the specific boundary conditions representing water transport in breadfruit drying. Moisture diffusivity is one of the important physical transport properties that are useful in the analysis of basic techniques of food processing operations such as drying and frying. This diffusion phenomenon is very complex. Theoretically, it is challenging to predict moisture diffusivity because each food ingredient's structure, water content, and chemical content are different and varied. Therefore, it is necessary to obtain such data through experimental procedures. (Cranck, 1979; Correa et al., 2017)

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provides an excellent overview of the mass transfer model based on the Fick diffusion differential equation with experimental data. This equation is generally used to describe the mass transfer on the surface by convection through the diffusion process by replacing the value of the diffusion coefficient with the effective diffusion coefficient.

Research on determining the moisture diffusivity of biscuits baked at different temperatures in the oven has been published by Demirkol et al., 2006 also using Fick's second diffusion equation. This research concluded that the effective diffusivity of biscuit moisture increased with increasing temperature and time. Simal et al., 2005 also used the Arrhenius equation to determine the diffusion coefficient value of drying kiwi fruit. The value also varied or changed from 3×10^{-10} m^2s^{-1} (at 30°C) to $17{,}21 \times 10^{-10}$ m^2s^{-1} (at 90°C). Simultaneous heat and mass transfer through the diffusion process during drying will cause various changes in food ingredients, including chemical changes such as water loss, starch gelatinization, aromatization, and color changes through Maillard hydrolysis and oxidation reactions. To minimize this, a blanching process or preheating is carried out at a temperature of less than 100°C for several minutes using hot water or steam. Blanching is one of the methods used to inhibit enzyme activity in vegetables and some fruits before and after processing.

According to Pujimulyani *et al.*, 2010 blanching aims to maintain product quality by deactivating oxidative enzymes (peroxidase and catalase enzymes, polyphenol oxidase, and lipoxygenase) found in foodstuffs. The enzyme is deactivated because it can interfere with the food quality during further processing. Another goal is to extend shelf life, kill some bacteria and deactivate enzymes that cause spoilage in foodstuffs. The right blanching treatment can have many benefits, including avoiding unwanted changes, reducing microbial content, maintaining color, softening tissue, helping to expel cellular gases in the tissue to prevent corrosion, and improving the texture of dried food (Winarno., F.G. 2002; Patel 2019). Blanching can be done in two ways: direct heating with hot water (Hot Water Blanching) or steam (Steam Blanching). The purpose of blanching also varies depending on the material used and the next process's purpose (Muchtadi et al., 1997; *Penelitian et al.*, 2006).

II. MATERIAL AND METHOD

A. *Raw Material*

Fresh breadfruit (Artocarpus altilis) was obtained from Bone Regency, South Sulawesi. Breadfruit is selected considering the size and does not show any damage after being washed with water and NaCl solution with a concentration of 0.5%. Breadfruit was cut into dice/chips with dimensions (0.02 × 0.02 × 0.02 m) for further analysis.

B. *Breadfruit Drying Experiment*

Breadfruit chip slices were treated with non-blanching and blanching—1% NaCl solution was prepared in 750 ml of distilled water. A total of 250 grams of breadfruit that have been reduced to ±2 mm in size are then put in 1% NaCl solution, then heated in a water bath at 40 °C, 60 °C, and 80 °C with a soaking time of 15 and 30 minutes. The purpose of blanching is to inactivate enzymes, reduce the number of microbes in the material, and improve product color. Blanching is usually done on vegetables and fruits that will be canned or dried. Blanching is a thermal process and generally requires temperatures ranging from 75 - 95°C (Gardjito, 2011; Marchianti et al., 2017)

After the heating process is complete, the breadfruit is drained using a filter, and then the drying process is carried out using a tray dryer with a drying air speed of 2 m/s and a temperature variation of 55°C and 65°C. The weight of the sample was measured at intervals of 30 minutes until the water content was constant for each treatment.

C. *Determination of Humidity Ratio.*

Water content (kg water/kg dry matter) is determined using the following equation

$$X = \frac{(\omega_0-\omega)-\omega_1}{\omega_1} \qquad (1)$$

where,

w_0 is the initial weight of the sample, w is the amount of water evaporated, and w_1 is the weight of the dry matter of the sample. The humidity ratio (M.R.) is defined as follows:

$$\mathrm{MR} = \frac{(X-X_e)}{(X_0-X_e)} \qquad (2)$$

Where X_e is the equilibrium water content and Xo is the initial water content

D. *Effective Moisture Diffusivity and Activation Energy*

Effective diffusivity (*D*eff) describes the moisture profile/movement of the foodstuffs, regardless of the mechanism involved. The drying profile description includes the initial drying stage, the constant rate period, and the decreasing rate period. In most stages of implementation, the third period dominates, i.e., the rate of decline (Dincer & Dost, 2007). According to Dincer & Dost, 2007, the mechanism of moisture movement in hygroscopic solids/materials at decreasing rate can be represented by a diffusion phenomenon according to Fick's second law. One-dimensional diffusion is a good approximation method and is considered very practical. Thus, the diffusion of water vapor in an unsteady state based on Fick's second law can be expressed as

$$\frac{\partial X}{\partial t} = \nabla.(D_{eff}\nabla X) \qquad (3)$$

where X is water content (kg water/kg dry matter), t is drying time, and eff is effective diffusivity (m2/s). To solve this partial differential equation, assume that; The initial water content is uniform throughout the surface of the dried material, thermal equilibrium occurs between the surface of the material and the drying air, and the shape of the material remains uniform during drying.

The general solution of (4) can be derived for the geometric shape of a cube using the appropriate boundary conditions (Crank_1975_Diffusion_2.Pdf, n.d.)

$$MR = \frac{(X_t - X_e)}{(X_0 - X_e)} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^2}\exp\left(-(2n-1)^2\frac{\pi^2 D_{eff} t}{L^2}\right) \quad (4)$$

In most cases, the effective diffusivity is estimated using only the first term of the general solution; thus, equation 5 can be simplified to:

$$MR = \frac{(X_t - X_e)}{(X_0 - X_e)} = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff} t}{L^2}\right) \quad (5)$$

The general form of (6) can be written in the following logarithmic form:

$$\ln(MR) = A - B * t \quad (6)$$

Where the constant B is $\pi^2 D_{eff}/L^2$ for the cube.

The variation of the effective diffusivity of water with temperature can be solved using the Arrhenius equation:

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{RT}\right) \quad (7)$$

The activation energy can be determined from the plot of $\ln(D\text{eff})$ versus $1/T$. The slope of the line is (Ea/R), and the point of intersection is $\ln(D\text{o})$.

a. *Statistical Analysis*

Regression analysis and 3D graphs of the value of Deff, MR, and temperature using python 2.7 software with the matplotlib library, NumPy axis 3D. The model was evaluated using various statistical parameters such as correlation coefficient (R^2) and standard error (s).

III. RESULTS AND DISCUSSION

A. Drying Curve

The data on the weight loss of breadfruit is then converted into data on the decrease in water content which is then converted into data on drying rate (L.P.) and moisture ratio (M.R.) displayed in graphical form. To consider how drying characteristics are, a drying curve can be drawn from a plot of drying rate versus water content. Figures 1 and 2 show the variation of drying water content with time for different drying temperatures.

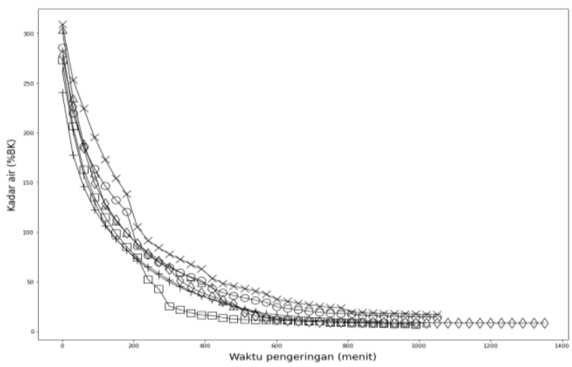

Fig 1:- The moisture content at a drying temperature of 55 °C

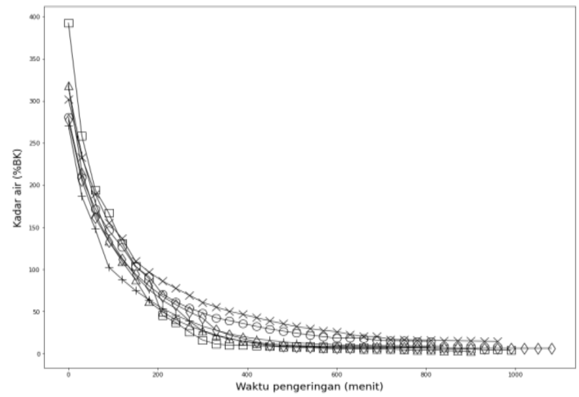

Fig 2.:- The moisture content at a drying temperature of 65 °C

Dry room temperature is one of the main factors in the drying process, which regulates the capacity of the air to remove moisture from food. Increasing the temperature of the drying chamber causes the water to evaporate faster than the wet surface and decreases the material's moisture content (Fellows, 2009).

Drying time is greatly influenced by the increase in temperature that occurs, as well as the drying rate. From the pattern of decreasing water content, it can be seen that the higher the temperature of the drying chamber, the shorter the drying time, and the higher the heat energy carried by air, the more mass of liquid evaporated from the surface of the material.

The research data shows that the higher the drying chamber temperature, the faster the time needed to dry the material.

Joko et al. 2012; Aisah et al., 2021 stated that the higher the drying chamber temperature, the greater the difference between the air vapor pressure and the material vapor pressure. The process of moving water vapor from the material to the surrounding air will be faster.

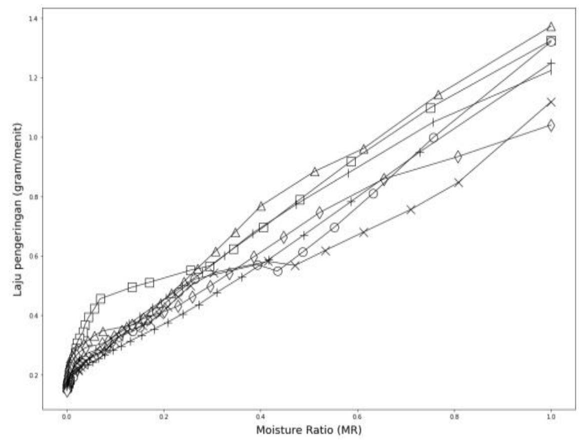

Fig 3:- Drying rate versus humidity ratio at a drying temperature of 55 °C

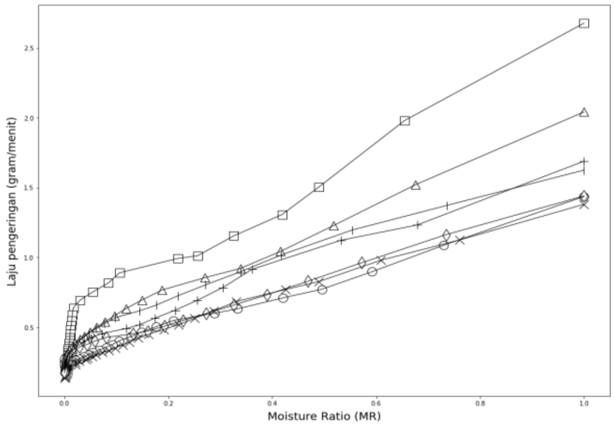

Fig 4:- Drying rate versus humidity ratio at drying temperature of 65 °C

The experimental results in Figures 3 and 4 show that drying occurs for two periods almost in a straight line, regardless of the actual drying conditions.

The plot of drying rate against humidity ratio shows low product moisture content. Therefore, the drying process in the continuous decreasing rate (second period) is not visible. The drying process only occurs when the drying rate decreases or during the first period (Maskan, 2001)

During this drying period, water movement to the surface can occur through different mechanisms. Surface diffusion is insufficient to maintain or cover the entire surface area of the material. During this period, mass transfer on the surface and moisture migration through diffusion.

B. Effective diffusivity and activation energy

The effective diffusivity of a material is the shortest distance required for material with moisture to carry out the evaporation process into the environment.

Figures 5 and 6 show drying experimental data plot the logarithm of the humidity ratio (M.R.) against time for different air temperatures. In each sample treatment, the moisture diffusivity value is estimated using the slope derived from linear regression ln (M.R.) with respect to time. Variation of $\ln(D\text{eff})$ versus $(1/T)$ for breadfruit drying with two different temperatures.

Experimental analysis of the data revealed a linear relationship between these parameters. The correlation coefficient ($R2$) of the experimental data was obtained as 0.9356 and 0.9618 for drying temperatures of 55 °C and 65 °C. The value of the activation energy for breadfruit is 58,509 - 68,530 kJ/mol at a drying temperature of 55 °C and 65,666 - 69,661 kJ/mol for a drying temperature of 65 °C. The diffusivity values obtained above take into account the shrinkage effect during drying.

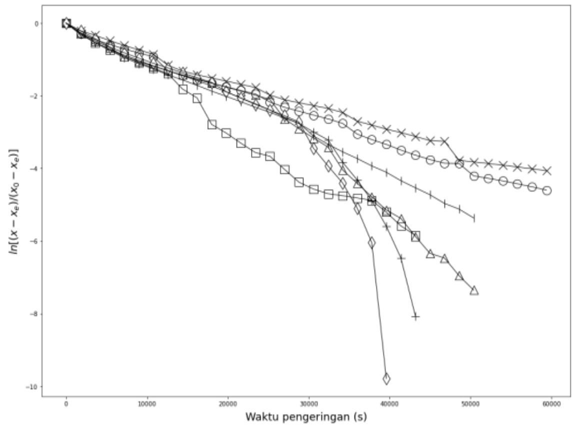

Fig 5:- Effective diffusivity of breadfruit on drying at 55 °C

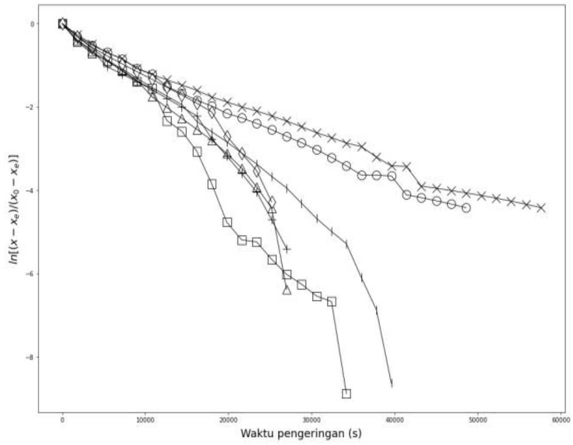

Fig 6:- Effective diffusivity of breadfruit on drying at 65 °C

Moisture gradients that occur during drying will produce pressure or disturbances in breadfruit's cellular structure or cell walls, resulting in changes in the physical structure that causes changes in shape, dimensions, or changes in the volume of the material (Major & Sereno, 2004). The cell wall disruption then affects the distance of the spread of water vapor that moves from the inside to the outside. Thus, this factor must be incorporated into a mathematical model to predict the sample's moisture content during drying accurately or to determine the effective diffusion coefficient correctly. The modeling curve of breadfruit drying for two different temperatures is presented in Figure 7. The correlation between effective diffusivity and humidity associated with product temperature is related through the Arrhenius equation.

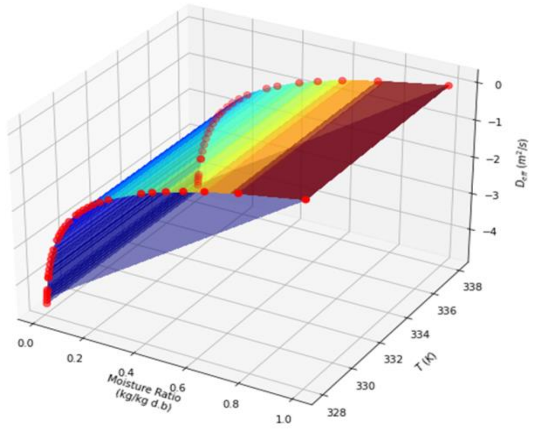

Fig 7:- Experimental simulation of effective moisture diffusivity with blanching

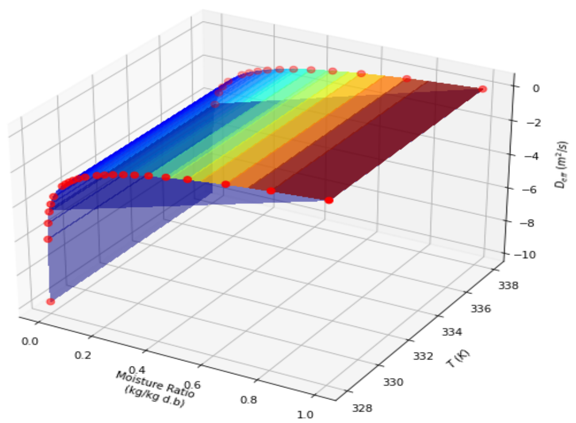

Fig 8:- Experimental simulation of effective moisture diffusivity without blanching

The coefficient of effective diffusivity increases with increasing temperature and water content. At high temperatures, water molecules bind freely to the food structure; therefore, it requires less energy to be removed than at lower temperatures (Xiong et al., 1991; Touil et al., 2014).

The increase in the effective diffusivity of breadfruit is in parallel with the increase in drying temperature. An increase in temperature results in a decrease in water viscosity and fluid outflow resistance (Torki-Harcheganiet et al., 2016a; Shah et al., 2020). In addition to a decrease in water viscosity, an increase in temperature will increase the heating energy and activity of water molecules (Alara et al., 2019), and an increase in the vapor pressure in the material will accelerate the transfer of moisture from within (Miraei Ashtiani et al., 2017).

The effective diffusivity value of breadfruit is still in the range of the effective diffusivity of food ingredients, which is between 10^{-13}-10^{-6} m^2s^{-1}, with the majority being in the range of 10^{-12} –10^{-8} m^2s^{-1} (Syah et al., 2020).

IV. CONCLUTION

The shrinkage value for breadfruit during drying was determined from the experimentally linear relationship between shrinkage versus moisture content. This shrinkage value is entered into the diffusion model to determine the effective diffusion coefficient. The effective moisture diffusivity values for drying breadfruit are in the highest and lowest ranges of 1.29823^{-11} m^2/s and $6.49114^{-12} m^2/s$. The correlation of the moisture diffusivity associated with the temperature of the material can be calculated using the Arrhenius equation. The breadfruit's highest and lowest activation energy values were 69,661 kJ/mol and 58,509 kJ/mol, respectively.

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