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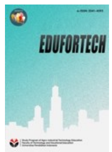

Analisis Kinerja Pengeringan Sale Pisang Menggunakan *Tray Dryer* dengan Pemodelan Matematika

Evaluation of Banana Sale Drying Performance Using a Tray Dryer with Mathematics Modeling

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A B S T R A K

Proses pengeringan Sale Pisang melibatkan dua pemodelan matematika, yaitu model Newton dan Henderson-Pabis. Sale Pisang dipotong dan dikeringkan selama 220 menit pada suhu 60°C dengan laju pengeringan 4,5 m/s, dengan pengamatan setiap 20 menit. Penelitian mencakup analisis kadar kelembaban, tekstur, dan perubahan massa Sale Pisang. Pemodelan menggunakan model Newton dan Henderson-Pabis menunjukkan hasil yang signifikan. Koefisien laju pengeringan (k) pada kedua model adalah 0,00335, dan nilai R^2 untuk keduanya adalah 0,98961 dan 0,98987. Hasil ini menunjukkan bahwa kedua model tersebut cocok secara teoretis untuk menjelaskan proses pengeringan Sale Pisang, memberikan kontribusi penting dalam memahami dan mengoptimalkan proses ini.

Kata kunci:
henderson-pabis model, newton model, sale pisang

A B S T R A C T

The drying process of Banana Sale involves two mathematical modeling approaches: the Newton model and the Henderson-Pabis model. The bananas are sliced and dried for 220 minutes at a temperature of 60°C with a drying rate of 4.5 m/s, and observations are made every 20 minutes. The research includes the analysis of moisture content, texture, and mass changes in banana chips. The modeling using the Newton and Henderson-Pabis models shows significant results. The drying rate coefficient (k) in both models is 0.00335, and the R^2 values for both models are 0.98961 and 0.98967. These results indicate that both models are theoretically suitable for explaining the banana chips drying process, providing essential insights for understanding and optimizing this process.

A R T I C L E I N F O

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1. INTRODUCTION

The economic growth of a country is often measured through the industrial and agricultural sectors. In many developing countries, agriculture plays a significant role in generating income and providing employment for millions of people. One agricultural commodity with substantial potential is bananas. Bananas are tropical fruits widely consumed by people all around the world. Bananas are one of the popular tropical fruits consumed worldwide. Their rich nutritional content and sweet taste make them a favorite among many people. However, bananas have a high-water content, which gives them a limited shelf life.

East Java Province has succeeded in becoming the province with the highest fruit production, one of which is bananas (Imanuel *et al*., 2021). Based on data from the Central Statistics Agency (BPS), banana production in 2022 will reach 2.62 million tons out of the total national production of 9.24 million tons. Banana (*Musa paradisiaca*) is a very popular fruit and is consumed worldwide (Irianto & Sudarmin, 2020). Bananas also contain numerous nutrients that are beneficial to health, such as high sources of carbohydrates, minerals, vitamin B6, and vitamin C (Luthbis & Ratnasari, 2020). Additionally, bananas contain the antioxidant dopamine (Wulandari *et al.*, 2018). Bananas are one of the agricultural products that have a short shelf life, typically ranging from only 21 to 30 days. As a climacteric fruit, bananas naturally produce ethylene gas, which accelerates the fruit ripening process. Overly ripe bananas have the potential to spoil and can no longer be consumed (Widodo *et al.*, 2019). Therefore, to anticipate this issue, product diversification is needed through various forms of banana processing, such as Banana Sale.

Banana Sale is a traditional food that holds great potential among Indonesian people (Syukran *et al*., 2019). However, the processing of Banana Sale still relies on traditional methods (Seftianti & Imam Abdul Aziz, 2021). The typical process involves placing the bananas in a roasting area and using wood or coconut shell fuel, which can be time-consuming. Unfortunately, traditional Banana Sale processing has several drawbacks. Firstly, it leads to uneven maturity levels of the bananas. Secondly, the smoking process results in an unpleasant aroma. Lastly, due to processing in an open area, cleanliness is less than optimal, and the bananas may get contaminated with smoke. These issues can significantly impact the quality of the final product (Ruddin, 2018).

With the continuous development of technology, various drying methods have emerged, offering alternative approaches to optimize the drying process (Naknaen *et al.*, 2016). Drying process usually utilizes sunlight which is a conventional method that is commonly used because Indonesia has potential solar energy that can be utilized for the drying process (Wardhani *et al.*, 2023). However, the drying process using sunlight has its disadvantages as it depends on weather conditions, humidity and product hygiene. Therefore, one solution is needed so that the drying process can continue to be carried out, such as by using various technologies, including tray dryer.

One such method is the tray dryer, which utilizes a multilevel drying technique with hot air flow (Fadilah *et al*., 2022; Muharja *et al.*, 2023; Wardhani *et al.*, 2023; Zikrillah *et al.*, 2023). Primarily employed for drying solid foodstuffs like fruits, vegetables, and spices, the tray dryer offers promising results (Das & Das, 2019). In this method, the material to be dried, in this case, Sale Banana, is spread on trays and arranged on shelves within the drying chamber. A blower facilitates the continuous circulation of hot air across the material's surface, effectively promoting the evaporation of water. As a result, the moisture content of the material decreases significantly (Anandharamakrishnan & Ishwarya, 2019). This study aims to evaluate the performance of the tray dryer in dehydrating the water content of Sale Banana, utilizing mathematical modeling to achieve the desired results.

2. METHODOLOGY

2.1. Equipment and Materials

The main equipment used in this research is a rectangular-shaped tray dryer equipped with perforated metal shelves, as shown in **Figure 1.** The drying shelves serve as containers for banana sale inside the drying chamber. The tray dryer is equipped with supporting tools such as a thermometer for temperature control, a fan, and a fan speed controller displayed on the temperature screen for T1, T2, T3, T4, and a weighing scale. The specific model used for the equipment is SF-25H, with dimensions of 250 mm, a capacity of 42 m3/min, power of 190 watts, and a voltage of 220-240 volts. The tray dryer consists of power heater button (1), temperature control and reading (2), fan power button (3), fan speed controller (4), temperature reading controls for T1 – T4 (5), temperature display screen (T1 - T4), T1 (7), T3 (8), T3 (9), T4 (10), weighing scale and material mass reading (11), and tray placement (12).

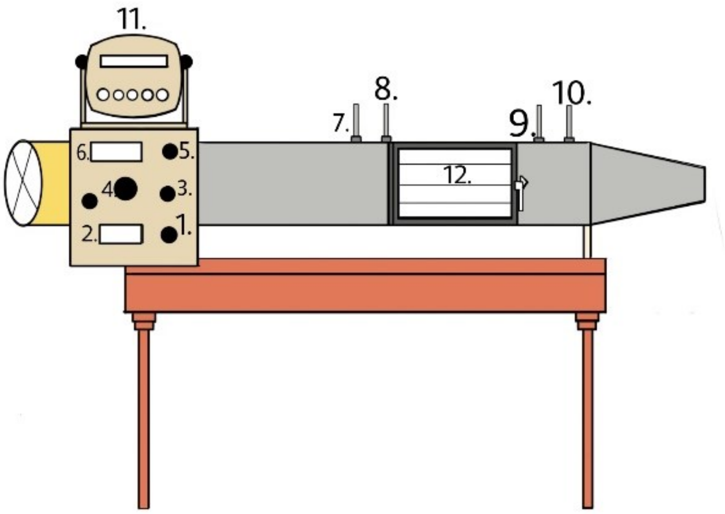

Figure 1. Tray Dryer Equipment Design

2.2 Research Procedures

The research was conducted between January and February 2023 at the Chemical Engineering Operations Laboratory, Faculty of Engineering, University of Jember. The experimental setup included a tray dryer equipped with a fan, heater, scales, trays, and a water reservoir. Before starting the experiment, the tray dryer was turned on to stabilize its temperature and humidity. The material used in the study was Banana Sale obtained from Tanjung Market, Jember Regency, East Java, Indonesia. The bananas were peeled and cut using a kitchen knife according to the specified variables.

A fixed drying time of 220 minutes was used for all experimental runs, with observation intervals set at every 20 minutes (0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220). The tray dryer's temperature was maintained at 60°C, and the drying rate was set at 4.5 m/s. For each variable, the Banana Sale samples were arranged in trays based on their respective weights, ensuring they were not too densely packed. The drying process was carried out at 60°C for 220 minutes for each variable.

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The research parameters included moisture content, texture, and mass changes in the Banana Sale samples. The data obtained from the experiment were analyzed using the ANOVA (Analysis of Variance) test, with assistance from Microsoft Excel 2019 and Origin Graph 2021 computer programs. The ANOVA test was used to determine the effect of the drying parameters on the results. Additionally, the regression coefficient was calculated to perform the statistical analysis of the data.

3. RESULTS AND DISCUSSION

3.1 *Tray Dryer*

Tray dryer is a drying equipment used for drying large quantities of solid or liquid materials. It consists of multiple shelves or trays where the materials to be dried are placed. The tray dryer is equipped with a temperature and humidity control system that can be adjusted according to user requirements. The drying process in the tray dryer is carried out by heating the air, which is then circulated into the drying chamber. This heated air flows through the materials to be dried, extracting moisture from them. The air, now laden with moisture, is then expelled from the drying chamber and directed outside.

Tray dryers offer several advantages over other drying equipment. One of them is their ability to dry large quantities of materials in a short amount of time. Additionally, tray dryers are easy to operate and can be adapted to various types of materials to be dried. However, there are certain considerations that need to be taken into account when using a tray dryer. Firstly, users must ensure that the materials to be dried are properly prepared and do not contain impurities or foreign objects. Secondly, users need to ensure that the temperature and humidity settings are appropriate for the specific type of material being dried. Lastly, regular cleaning of the tray dryer is necessary to prevent contamination of the materials being dried. In essence, tray dryers are effective and efficient drying tools for processing large quantities of materials. They can be adapted to various types of materials and are user-friendly. However, users must pay attention to important factors to ensure optimal results when using a tray dryer.

3.2 Effect of Drying Time on Moisture Content and Material Mass

The drying time affects two crucial factors in the drying process of materials: moisture content and material mass. In the context of food processing, pharmaceuticals, and various other industries, a deep understanding of the drying process is essential. The moisture content in a material is one aspect that affects the quality and shelf life of the final product. The lower the moisture content in a product, the longer it can endure without spoilage, retaining its organoleptic qualities. Material mass, on the other hand, refers to the total weight of the material undergoing the drying process. Changes in material mass reflect how much water has been removed from the material during the drying process.

It's important to understand that drying time is a key factor influencing these parameters. When the material is placed in the drying apparatus, the drying process commences. The water contained in the material begins to evaporate due to exposure to specific temperature and airflow. This process does not happen instantly; instead, it takes a certain amount of time for the water to diffuse from inside the material to its surface and eventually evaporate. With an extended drying time, there is a gradual reduction in the moisture content of the material. This is the primary focus of this research: understanding how the reduction in moisture content correlates with the time taken. In the initial phase of the drying process, when the material has high moisture content, the reduction occurs rapidly. The surface water evaporates first, resulting in a significant weight loss. However,

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over time, the reduction in moisture content becomes slower. This is because water has to diffuse from inside the material to its surface before eventually evaporating into the air. This diffusion process takes longer as water must penetrate the dense material structure.

Finding the right balance point in the drying process is crucial. Too short a drying time can leave the product incompletely dried, with high moisture content. Conversely, if the drying time is too long, the material can experience over-drying, where its moisture content drops to undesirable levels. Over-drying can lead to nutrient loss and alter the organoleptic characteristics of the product. Therefore, this research also includes exploration on finding the optimal drying time to achieve the desired moisture content without compromising the quality of the material. Concerning material mass, the changes occurring during the drying process also have significant implications. As the material undergoes drying, its weight decreases due to water evaporation. The curve depicting the reduction in material weight over time illustrates how this process unfolds. Initially, there is a rapid weight loss as surface water evaporates quickly. However, as time progresses, the weight reduction slows down due to the limitation posed by the diffusion of water from inside the material. Attaining a profound understanding of the pattern of material mass change over time is key to optimizing the drying process. Understanding when the mass reduction slows down can help determine when the drying time has been sufficiently long to achieve the desired outcomes.

It is also important to link this research to practical applications in various industries. In the food industry, the findings of this research can be utilized to enhance the production processes of dried foods such as banana chips, fruit crisps, dried nuts, and jerky. A better understanding of how drying time affects moisture content and material mass can aid in the production of stable products with a long shelf life.The drying time plays a crucial role in determining the moisture content and mass of the material, including Banana Sale (Ismiyati *et al*., 2018). In this research, the drying process was conducted until the moisture content of the Banana Sale reached the maximum allowable level of 40%, as specified in SNI 01-4319-1996, which outlines the quality standard for Banana Sale. To achieve this, the drying test was conducted at regular intervals of 20 minutes using a tray dryer. The tray dryer was set to a constant temperature of 60°C, and the drying rate was maintained at 4.5 m/s throughout the experiment. By monitoring the drying process every 20 minutes, researchers can track how the moisture content and mass of the Banana Sale change over time. This information is vital in understanding the drying behavior of the material and ensuring it meets the quality standards required for Banana Sale production. Changes in water content that occur in banana sales can be seen in **Figure 2.**

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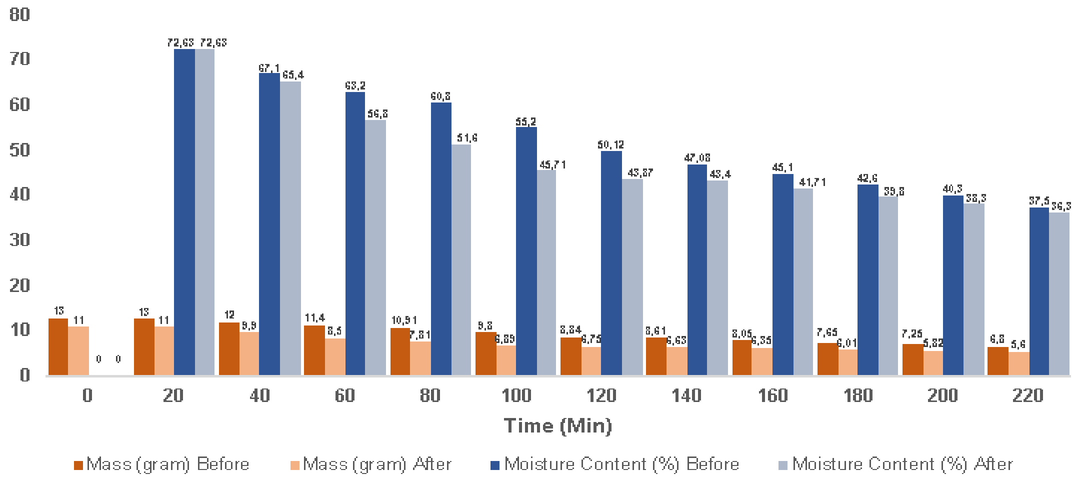

Figure 2. The Changes Moisture Content of Banana Sale

The drying time required for Banana Sale to reach its maximum water content reduction is 3 hours and 40 minutes, equivalent to 220 minutes. According to the research results in Figure 1, the water content and mass of Banana Sale decreased during the drying process. The initial water content of Sale Banana was 72.63%, and as drying progressed, it reduced to 36.3%. This decrease in water content is attributed to the disruption of the balance between the high-water vapor pressure within the material, which moves into the environment, leading to evaporation and thus reducing the water content of the Banana Sale.

Additionally, the drying time has an impact on the mass of Banana Sale. The initial mass of Sale Banana was 13 grams, and it decreased to 5.6 grams during drying. These changes occur due to the drying process, which alters the characteristics of the material, including its physical and chemical properties. Figure 1 demonstrates a direct proportionality between the decrease in water content and the reduction in mass of Banana Sale during drying. This correlation is explained by the reduction in water vapor pressure within the material and the environment. As a result, the longer the drying time, the more stable the weight becomes.

3.3 Mathematical Model

Drying is a crucial method in preserving food materials (Pratiwi, 2020). The use of mathematical models to analyze drying performance is a common approach in the food industry. In the context of banana sale drying using a tray dryer, two frequently employed mathematical models are the Henderson-Pabis model and the Newton model. Both of these models provide a mathematical representation of how the moisture content of banana sale decreases over time during the drying process.

A. Henderson-Pabis Model

The Henderson-Pabis model stands as a pivotal mathematical framework used to predict the drying rate of solid products during convective drying processes. This model, developed by J.M. Henderson and Stanislav Pabis in 1961, finds widespread application in both research and industrial sectors, aiding in comprehending and optimizing the drying process of various solid materials such as grains, vegetables, and other food products. It has the following general form of mathematical formula of the Henderson-Pabis model :

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$$\frac{X}{X_0} = e^{-kt^n} \tag{1}$$

In this equation, (X) represents the moisture content at a specific time, (X_0) is the initial moisture content, (k) is the drying rate constant, (t) denotes the drying time, and (n) signifies the order of the drying reaction. (X/X_0) signifies the ratio between the moisture content at a specific time (X) and the initial moisture content (X_0). This ratio reflects the extent to which the material has undergone drying at a given time. (k) represents the drying rate constant, indicating how rapidly the material is drying. The value of (k) is influenced by factors such as temperature, air humidity, and the physicochemical properties of the material being dried. (t) denotes the drying time in relevant units (usually hours). n represents the order of the drying reaction. A value of (n =1) indicates a first-order drying process, while (n = 0.5) signifies a half-order reaction. The value of (n) varies depending on the nature of the material being dried.

The advantages of this Henderson Pabis model are relatively simple and easy to use, especially for cases of convective drying on an industrial scale. Despite its simplicity, the model can provide reasonably accurate estimates in many drying scenarios. The model has limitations in depicting complex drying conditions, such as non-convective drying or micro-scale drying processes. Depending on experimental conditions, determining the value of the reaction order (n) can be intricate and may require empirical approaches. The Henderson-Pabis model finds applications across various fields, including the food industry, agriculture, and chemical engineering. In the food industry, the model is utilized to predict the drying time of grains, fruits, and other food products during the drying process. This is crucial for optimizing the drying process and ensuring the final products have the appropriate moisture content to maintain quality and shelf life. In the realm of agriculture, the Henderson-Pabis model is employed to assess the drying of agricultural products such as grains, seaweed, and other farm produce. This analysis aids farmers and producers in understanding the time required to efficiently dry their agricultural yields. In summary, the Henderson-Pabis model serves as a valuable mathematical tool in comprehending and optimizing the drying process of various solid products. Despite its simplicity, this model provides a solid foundation for drying analysis and continues to be widely used in both research and industrial applications.

B. Newton Model

The Newton model is a simpler model that assumes the drying rate of food material is proportional to the difference between the moisture content of the material (X) and the moisture content of the surrounding environment (Xa). This model can be expressed as follows:

$$\frac{dX}{dt} = -K \times (X - X_a) \tag{2}$$

This model states that the drying rate (change in moisture content) depends on the difference between the moisture content of the food material and the surrounding moisture content. The constant (K) is a parameter that describes the drying characteristics of the food material and the tray dryer used. Drying is a crucial aspect of the food processing industry. To enhance the efficiency of this drying process, the application of mathematical models such as the Newton model plays a pivotal role. In the context of drying Banana Sale using a tray dryer, the Newton model offers a profound insight into how the drying process occurs at a

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microscopic level. The Newton model is based on the law of convection, stating that the rate of change of temperature (or moisture content in this case) of a substance is proportional to the temperature difference (moisture content difference in this case) between the substance and its surroundings. In the case of drying Banana Sale, the Newton model asserts that the rate of moisture reduction (dX/dt) from the Banana Sale depends on the difference between the actual moisture content of the Banana Sale (X) and the surrounding moisture content, which is considered as the saturated moisture content (X_a).

In this formula, (X) represents the actual moisture content of the Banana Sale at a specific time. As the drying process progresses, (X) decreases continually as the water in the Banana Sale evaporates. On the other hand, (X_a) represents the surrounding moisture content or the saturated moisture content attained by the Banana Sale in equilibrium with their surroundings. When (X) approaches (X_a), the moisture content difference ($X-X_a$) becomes smaller, causing the drying rate (dX/dt) to slow down. This means that the closer the moisture content of the Banana Sale is to the saturated moisture content, the slower the drying rate becomes. This creates an efficient drying process where it proceeds rapidly initially when the moisture content difference is significant and slows down as the Banana Sale approach their saturated moisture content.

The application of the Newton model in the analysis of drying offers several significant advantages. Firstly, it allows researchers and producers to gain a deeper understanding of how the Banana Sale respond to the drying process. With this understanding, they can optimize the drying process, adjusting parameters such as temperature and air velocity in the tray dryer according to the unique characteristics of Banana Sale. By optimizing this process, producers can reduce the required drying time, thereby saving energy and production costs. Furthermore, the Newton model enables producers to exercise better control over product quality. By knowing how much the moisture content of Banana Sale decreases at each time point during the drying process, they can ensure that the Banana Sale reach the desired moisture content without experiencing over-drying or under-drying. This is crucial in ensuring the quality of the end product, as the correct moisture content affects the taste, texture, and shelf life of Banana Sale.

Additionally, the insights provided by the Newton model are invaluable in designing an efficient tray dryer. By understanding the pattern of moisture content change in Banana Sale over time, producers can adjust parameters such as temperature and air velocity in the tray dryer. An optimal design can reduce the drying time without compromising the quality of the product, creating efficiency in overall production. However, despite the valuable insights offered, the utilization of the Newton model also necessitates accurate and precise data. Proper data collection and precise measurements of the moisture content of Banana Sale during various stages of drying are crucial to ensure the accuracy of the model. Moreover, determining the value of the constant (K) also requires meticulous statistical analysis, involving techniques such as linear regression to ensure the model fits the experimental data accurately. The Newton model provides a robust mathematical framework for analyzing the drying performance of Banana Sale using a tray dryer. By understanding the change in moisture content of Banana Sale over time, producers can optimize the drying process, reducing time and production costs while ensuring consistent product quality. Therefore, the

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Newton model not only serves as a vital analytical tool in the food processing industry but also represents a step towards more efficient and sustainable production processes.

The application of models in analyzing the performance of banana sale drying using a tray dryer begins at the initial stage of analysis, where the initial moisture content of the banana sale (X_0) and drying time (t) data are collected during the drying experiments using the tray dryer. These data are then utilized to calculate the necessary constants for both models. The Henderson-Pabis model is employed to understand the relationship between drying time and the change in moisture content of banana sale. The constants (K) and (b) are computed using data fitting techniques, where the model is adjusted to experimental data. The results provide insight into how quickly the banana sale dries and how long it takes to reach a specific moisture content. Meanwhile, the Newton model offers insights into how the drying process correlates with the difference between the moisture content of the food material and the surrounding moisture content. In the context of banana sale, this could mean how the drying rate changes as the moisture content of the banana sale approaches the surrounding saturation moisture content. This model aids in understanding the drying process at the microscopic level.

The use of both these models provides distinct benefits in the analysis of banana sale drying performance using a tray dryer. The Henderson-Pabis model gives a macroscopic overview of drying time and moisture content changes, while the Newton model provides microscopic insights into the drying process at the molecular level. By comprehending both, manufacturers can design more efficient drying processes, optimize timing, and ensure the quality of the resulting banana sale products. Thus, the use of mathematical models like Henderson-Pabis and Newton becomes crucial in optimizing the drying processes for banana sale and other food products.

Mathematical modeling in drying Banana Sale using a tray dryer serves several crucial functions that aid in understanding and optimizing the drying process (Shomali & Abbasi Souraki, 2019). **Table 1** shows the results of the analysis of the constant values of each model. Two mathematical approaches are employed for predicting moisture content: Newton's method and the Henderson-pabis model. In the case of determining the moisture content of Sale Banana, the Henderson-pabis equation was favored. This research suggests that identifying the optimal operating conditions for the tray dryer is crucial in achieving effective and efficient dehydration of Sale Banana. An essential aspect of this process is the prediction of drying rates. Details of the results of mathematical modeling for drying banana sales are depicted in **Table 1.**

Table 1. Mathematical modelling of Banana Sale drying

Newton model			**Henderson-Pabis**			
K	R^2	x^2	K	a	R^2	x^2
0,00335	0,98961	19,9966	0,00335	77,3319	0,98987	4,77514E-17

The mathematical model enables us to forecast the drying rate of Sale Banana at different stages of the process. Understanding how the drying rate changes over time allows us to optimize process parameters, such as temperature, airflow velocity, or banana film thickness, to achieve the desired drying rate efficiently. Another valuable function of mathematical models is determining the time needed to reach a specific level of moisture content in the Banana Sale. This information is vital in planning the production process and

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ensuring that the final product meets quality standards. The mathematical modeling graph for drying banana sales is depicted in **Figure 3.**

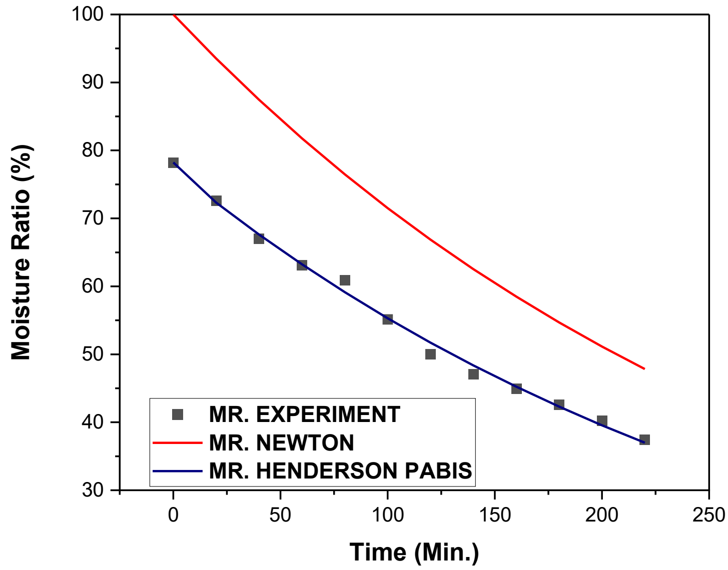

Figure 3. Mathematical modelling of Sale Banana drying

Newton's modeling of drying Sale Bananas using a tray dryer is a mathematical method that applies Newton's law of cooling to understand the drying process (Gandolfi *et al*., 2018). Newton's law of cooling states that the rate of change of temperature of an object is proportional to the temperature difference between the object and its surroundings. In the context of drying bananas, this means that the greater the temperature difference between the bananas and the surrounding air, the faster the drying process occurs. The investigation into drying kinetics demonstrated that solely declining rate periods were noted, implying that the principal mechanism governing the release of moisture was internal diffusion. Consequently, a higher value for the drying rate coefficient (k) and heat transfer leads to a faster drying process. Henderson-Pabis modeling is another mathematical method used to describe the drying process (Omolola *et al*., 2019). This approach attempts to establish a relationship between the rate of drying, the material's water content, ambient temperature, and certain constants relevant to the drying process. To obtain the tray dryer drying model, constant values k and other parameters are determined through nonlinear regression using Microsoft Excel software. **Table 1** presents the results of the analysis of the constant values for each model, and **Figure 3** displays the value of R^2 for each equation model. The R^2 values for both models indicate the significance of the drying process, demonstrating that the Newton and Henderson-Pabis models are appropriate for theoretically presenting Banana Sale drying.

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4. CONCLUSION

In this study, drying time plays a crucial role in determining the moisture content and mass of Banana Sales. Drying was carried out until the moisture content of the Banana Sale reached the maximum allowable level of 40%, by following the quality standard specified in SNI 01-4319-1996. The research results showed that the drying time required for Banana Sale to reach its maximum reduction in water content was 3 hours and 40 minutes, equivalent to 220 minutes. During the drying process, the water content and mass of Banana Sales decreased. This decrease is attributed to the drying process altering the material's characteristics, including its physical and chemical properties.

There is a direct correlation between the decrease in water content and the reduction in the mass of Bananas Sale during drying. Mathematical modeling in drying Banana Sales using a tray dryer serves several crucial functions that aid in understanding and optimizing the drying process. One of the primary functions is predicting the drying rate. The mathematical model enables us to forecast the drying rate of Banana Sales at different stages of the process. Understanding how the drying rate changes over time allows us to optimize process parameters, such as temperature, airflow velocity, or banana film thickness, to achieve the desired drying rate efficiently. Additionally, mathematical models are valuable in determining the time needed to reach a specific level of moisture content in Banana Sales. This information is vital in planning the production process and ensuring that the final product meets quality standards. In this study, two mathematical models, namely the Newton and Henderson-Pabis models, were used to understand the drying process of Banana Sale. Both models proved to be suitable and significant in theoretically presenting the drying process of Banana Sale.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The author confirms that this article is free from plagiarism.

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