P-ISSN 2586-9000
E-ISSN 2586-9027
Homepage : *https://tci-thaijo.org/index.php/SciTechAsia* Science & Technology Asia
Vol.29 No.3 July - September 2024 Page: [166-177]
Original research article

Effect of Radish (*Raphanus Sativus* L.) Height on Natural Drying Characteristics and Mathematical Modeling

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Received 7 February 2024; Received in revised form 25 July 2024
Accepted 20 August 2024; Available online 25 September 2024

ABSTRACT

The fresh vegetable radish (*Raphanus sativus* L.) is perishable due to its high water content of about 87%, and radishes spoil quickly. This study aimed to study the impact of variations in radish weight on drying time, ascertain the characteristics of radish drying with natural drying, and determine the mathematical model of radish drying. The measurements of the drying samples determined in this study for the radishes are a length of 4 cm, a width of 2 cm, and height of 0.5 cm, 1.0 cm, and 1.5 cm, which will be dried under sunlight or not exposed to sunlight. The results showed that the radish height of 0.5 cm responds to the decrease in mass during outdoor drying. The explanation of the radish drying process is arrived at by matching the research data of three model equations, namely the Newton, Page, and Henderson-Pabis models. Furthermore, the suitability was determined by the coefficient of determination (R^2). The Page model was the most suitable drying model to explain radish drying. The changes in the characteristics of the radish before and after the drying process were detected using a scanning electron microscope.

Keywords: Coefficient of determination; Drying model; Natural drying; Page; Radish

1. Introduction

Indonesia is a tropical country with diverse fruit, ornamental, and vegetable plants. Tropical climate conditions make several kinds of plants grow and live well [1]. Radish (*Raphanus sativus* L.) is a vegetable plant that looks like tubers and has short stems that force all leaves to fall to the

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doi: 10.14456/scitechasia.2024.54

ground [2]. Radish grows in tropical and temperate regions [3], which belong to the *Brassicaceae* family, genus *Raphanus*, and *species sativus* [4]. Radish has a chemical content that is very rich in fiber, flavonoids, essential oils, choline, iron, niacin, oxalic acid, and vitamins A, B1, and B2 [5], as well as a source of vitamin C (ascorbic acid) and minerals such as calcium, potassium, and phosphorus which are good for health [6]. Besides being rich in nutrients, radishes can be processed into various dishes [1].

Radish is easy to cultivate because it has excellent adaptation to be planted in the highlands or lowlands. A good soil structure for radish plants is crumbly, loose and has a high availability of nutrients [1]. Radish has different skin colors (red, purple, black, yellow, and white to pink), while the flesh is usually white. In addition, edible radish roots vary in shape, size, and length [1]. In the beginning, few people knew the benefits and processing of radish, therefore the public's desire to buy it was not as great as other vegetables. However, along with the latest research and information development, radish tubers have become the center of attention for herbal medicine [2]. Drying is one of the most widely used preservation methods, which involves evaporating most of the water contained in food materials using heat energy [7]. It is a process in which water is removed from food, by evaporation or sublimation, thus reducing the water availability for chemical, enzymatic or microbial degradation reactions [8].

Radish is classified as a perishable food ingredient. This is due to the very high water content of the plant product [9]. Radish drying is accepted as a simple method to improve the stability and extend the shelf life of radish [10]. Drying methods in general consist of two, namely manual drying and mechanical drying. Manual drying can be called natural drying and mechanized drying is called artificial drying. In natural drying, the drying heat is influenced by the surrounding air or sun while mechanical drying (artificial drying) uses additional heat [11]. Research on natural drying has been done before, such as drying ginger (*Zingiber Officinale Rosc.*) [12, 13], potatoes [14, 15], cucumber [16], and carrots [17, 18]. Research on mechanical drying has been conducted using a tray dryer on turmeric [19] and ginger [20].

Based on the thoughts described, the researcher wants to study of the effect of variations in size of radish on the rate of natural radish drying (*Raphanus sativus* L.). The natural drying method was chosen. After the drying process is carried out, the drying kinetics of radish will be obtained using 3 drying kinetics models, namely the Newton, the Page, and the Henderson-Pabis drying models.

2. Materials and Methods

2.1 Materials

The materials used in this study were aquadest and radish obtained from around Banjar Ganjang Village, Toba District, Sumatera Utara, Indonesia (2°28'22.4"N 99°11'19.3"E). The equipment used in this study were cutters, measuring cups, iron rulers, electric scales, and tarpaulins. Analysis of the radish morphology before and after the drying process was conducted by using a Scanning Electron Microscope (TM 3000) in UPT Laboratorium Penelitian Terpadu, Universitas Sumatera Utara, Medan, Indonesia.

2.2 Raw material preparation

Radish as much as 1 piece was measured using an iron ruler and cut using a cutter by size according to Table 1. Samples that have been cut according to size are then stored.

Table 1. Radish Size Variations.

Sample	Width (cm)	Length (cm)	Height (cm)
1	0.5		
2	1	4	2
3	1.5		

2.3 Raw material density determination procedure

The samples were weighed using an electric balance (Fig. 1). Then, the sample density was measured using a measuring cup. Distilled water was poured into a measuring cup as much as 30 mL. Next, the sample was put into a 50 mL measuring cup (Fig. 1), and then the volume change was recorded.

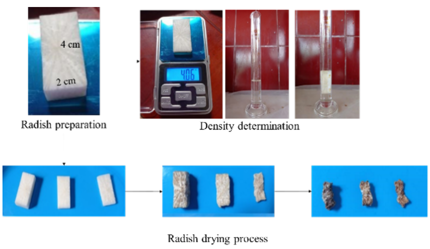


Fig. 1. Schematic diagram of the radish drying process conducted in this research.

2.4 Raw material drying process

Samples were weighed with each pre-prepared size using an electric balance. Then, the samples were placed on tarpaulins arranged with the predetermined sample height and the tarpaulins were placed indoors and outdoors. The drying process was carried out with the size parameter of the sample weight change. Weighing of the sample was done every hour until the sample reached a constant weight. After that, the sample was placed back in its original position and the drying process continued. The radish drying was conducted for 5 hours every day until the samples reached a constant amount of weight. The drying process started in local time at 10:00 am and ended after 5 hours at 3:00 pm. If it was raining, the outdoor drying was moved to the shade outside the room. During drying, the physical condition of the samples and air conditions were observed. This study's average daily ambient temperature was between 24°C - 28°C. For drying kinetics, the weight loss of the sample was measured with a digital balance until the sample reached a constant weight at predetermined time intervals. The lost weight of the sample was calculated using the Eq. (2.1) [13,21].

$$WL_{(t)} = W_{(0)} - W_{(t)}, \qquad (2.1)$$

where $WL_{(t)}$ = weight of the reduces sample at a given time interval, $W_{(0)}$ = initial weight of sample (before drying), $W_{(t)}$ = dry weight of the sample at a given time interval.

2.5 Determination of drying mathematical model

Kinetic models are one way to control the process and predict what drying conditions are appropriate for the materials used [22]. They also predict the relationship between mass transfer and drying time. The following drying models are frequently utilized mathematical models: the Newton, the Page, and the Hederson-Pabis drying models. The mathematical equations of these models are then converted into linear form. Table 2 shows the linear form of these mathematical models.

The parameters a, k, and n were calculated by non-linear regression analysis using the Excel Solver program (Microsoft Office Excel, Professional Edition). The agreement between the predicted and exper-

Table 2. Drying Kinetics Model [23].

Model Name	Model Equation	Linear Shape	Height (cm)
Newton	$MR = \exp(-kt)$	$\ln MR = -kt$	
Page	$MR = \exp(-kt^n)$	$\ln(-\ln MR) = \ln k + n \ln t$	2
Henderson-Pabis	$MR = a\exp(-kt)$	$\ln MR = \ln a - kt$	

imental data was evaluated based on statistical analysis [24].

3. Results and Discussion

3.1 Physical properties of radish

In this study, density measurements were carried out on samples with various size variations. Each sample was weighed and its volume measured. The data obtained can be seen in Table 3. Weight and volume data can estimate the density of each sample. After weighing and measuring, the overall density obtained is 0.988 g/ml. The radish's physical properties have similar densities, suggesting a relatively uniform composition. The radish is slightly less dense than water (which has a density of 1 g/ml), suggesting that radishes are composed mainly of water but with some solid content. Research on other food products, such as mango foams, indicates that the material's initial density influences its effective moisture diffusivity [25]. Lower densities can lead to higher diffusivity and shorter drying times, which suggests that similar principles apply to radishes.

3.2 Radish drying on day one

The first day of the drying process shows a decrease in water content relatively quickly and in large quantities. This is because the water that evaporates is free water found on the surface of the material [26]. Fig. 2 shows the drying of radish on the first day, both inside and outside.

Fig. 2 shows the decrease in the radish weight during the drying process for 5 hours. In outdoor conditions, Sample 1 (0.5 cm height) initially weighed 4.06 g and it weighed 1.82 g five hours later. Sample 2 (1.0 cm height) initially weighed 6.7 g and it weighed 3.56 g five hours later. Sample 3 (1.5 cm height) initially weighed 3.65 g and it weighed 2.70 g five hours later. Sample 2 (1.0 cm height) the initial weight was 6.65 g and the weight became 5.97 g five hours later. For Sample 3 (1.5 cm height), the initial weight was 10.42 g and the weight became 9.08 g five hours later. It can be seen that some of the weight in the sample has been lost to the air, whereas the weight that has been lost is the moisture content in the sample.

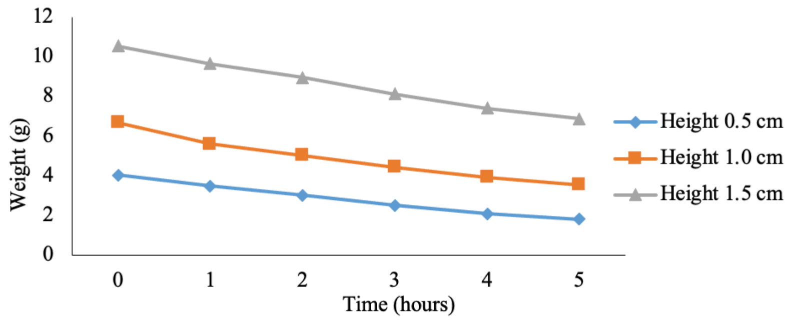
The results obtained show that the first day drying process shows a relatively rapid decrease in water content and in large quantities. This is because the water that evaporates is free water found on the material's surface [26]. Two factors affect the drying rate, namely internal factors, such as the shape or size of the material, and external factors, such as temperature, humidity, air speed, and air direction [27]. The research results obtained show that each height of material takes a different time to reach its equilibrium limit. The difference in the height of the radish material shows that the greater the height the material, the longer the drying time. Therefore, the variable differences in sample size and time resulted in different kinetics of drying for every sample.

3.3 Radish weight loss per day

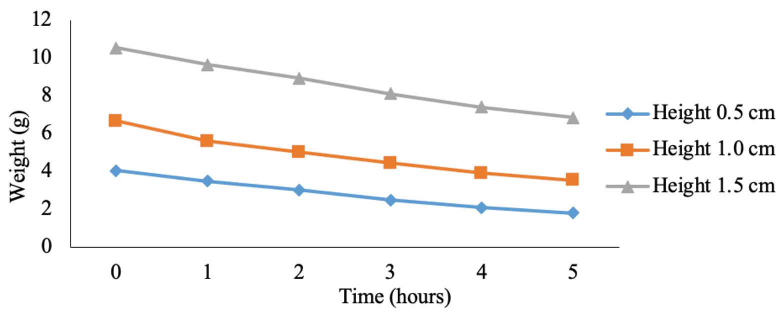
The weight loss in the radish sample shows that the water content will decrease until it reaches equilibrium. Drying kinetics decreased with time. Radish drying data from the first day to the end of the drying process with outdoor and indoor conditions can be seen in Fig. 3.

Table 3. Identification of Radish Physical Properties.

Sample	Height (cm)	Length (cm)	Height (cm)	Weight (g)	Volume (ml)	(g/ml)
1	0.5			4.06	4.2	
2	1	4	2	6.7	6	0.988
3	1.5			10.55	12	



(a)



(b)

Fig. 2. Effect of weight change of radish throughout the first day drying time in (a) Outdoor and (b) Indoor.

In outdoor conditions, the weight of sample 1 was constant on day 4 with a weight of 0.22 g; the weight of sample 2 was constant on day 6 with a weight of 0.37 g; and the weight of sample 3 was constant on day 8 with a weight of 0.57 g. In sample 1, the weight loss from the beginning of drying to the end of drying on day 8 was 3.84 g. In sample 2, it was 6.33 g, and sample 3 was 9.98 g. When the sample was inside, the weight of sample 1 was constant on day 7 with a weight of 0.25 g, the weight of sample 2 was constant on day 12 with a weight of 0.37 g, and the weight of sample 3 was constant on day 15 with a weight of 0.54 g. In sample 1, the weight loss from the beginning to the end of drying on day 15 according to the equation was 3.4 g. For sample 2, it was 6.28 g, and sample 3 was 9.88 g.

Fig. 3 shows that moisture content decreases or stays lower the longer the drying process lasts. In the drying process, the longer the material is dried, the more moisture content will decrease to a limit of the balance of the material's wetness [28]. When radish is dried outside, it takes 4-8 days to reach its equilibrium weight, and drying indoors takes 7-15 days. This indi-

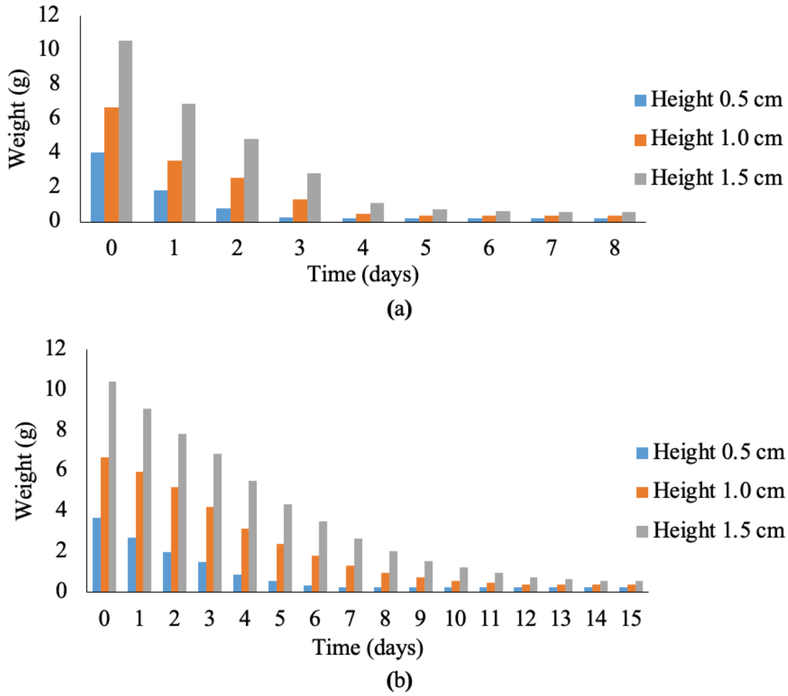


Fig. 3. Effect of change in weight of radish drying per hours in (a) Outdoor and (b) Indoor settings.

cates that the drying rate is related to the factors affecting drying, including drying air factors and material properties. Previous research on drying carrots outdoors under sunlight has the most significant weight loss value in round and 1.0 cm thick samples with a total loss of 16.76 mg [18]. In drying turmeric using an oven, the most significant decrease was obtained at a turmeric thickness of 5 mm, namely 720 minutes at 70°C [30]. Factors related to drying air are temperature, volumetric velocity of drying air flow, and air humidity. In contrast, factors related to material properties are material size, initial moisture content, and partial pressure in the material [29]. The drying kinetics of the size variable of 0.5 cm for outdoor and indoor as showed in Fig. 4

Fig. 4 shows a comparison of the drying kinetics of samples at a height of 0.5 cm in outdoor and indoor conditions. Drying of the samples was carried out for 5 hours, starting from 10:00 to 15:00 WIB, and the samples were weighed every 1 hour. After 15:00 WIB, all samples were stored in an airtight container and dried the next day at the same time and under the same conditions as the previous day until the sample weight was balanced/constant. The drying temperature obtained in this study is 24-28°C. As shown in Fig. 4, it is explained that the greatest overall reduction in weight occurs in outdoor drying conditions. The best condition for drying materials is an open condition directly exposed to sunlight. The higher the temperature of the drying air, the more heat energy the air carries, so that the amount of evaporated material water mass is more significant [31]. During the drying operation, heat and mass transfer causes the escape of water by heat passing through the surface of the sample.

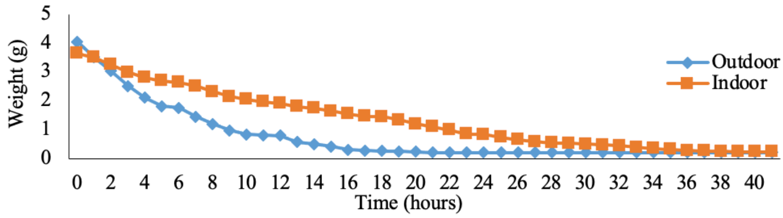


Fig. 4. Effect of weight change on drying of samples with a height of 0.5 cm.

3.4 Characteristics of radish drying results

One of the significant physical changes during drying is the material's volume decreasing. Heat and water loss cause the material's structure to change shape and decrease in size. The physical changes in the radish samples can be seen in Fig. 5.

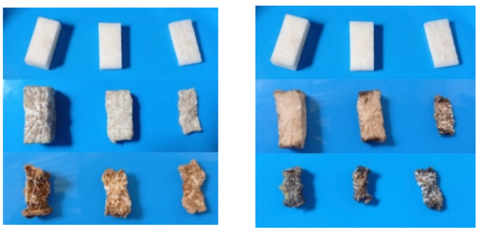


Fig. 5. Shape and surface of radish before and after drying in (a) Outdoor and (b) Indoor settings.

Fig. 5 illustrates how the sample's surface and shape changed before and after drying. Shrinkage is caused by modifications to the sample's surface structure and the sample's water release. The material will shrink if its volume decreases, shape changes, and hardness rises. The temperature and moisture content of the material during the drying process have an impact on shrinkage. The shrinkage increases with the amount of water that escapes the material. The drying process causes the material's previously water-filled holes to become linked, causing the material's outer surface to shrink inward and lose surface area [32]. It can be seen that drying greatly influences the physical texture and color of the sample [33].

Drying has a very significant effect on changes in surface morphology in dried radish. Changes in the surface structure of the radish sample, along with the reduction of the water content in the radish, cause the color of the sample to become dark (brownish) and the formation of wrinkles on the surface of the sample. Fig. 6 illustrates that the sample's surface structure changed before and after drying.

The accompanying figure displays the findings of the SEM characterization of the radish samples. The surface of the radish before and after drying is depicted in Fig. 6. The radish's surface seems hollow and full of water before drying, but once it dries, the cavities that once held water link to one another, causing the radish's outer surface to shrink inward and lose surface area [32]. Dried radish undergoes notable surface and color changes as a result of drying. In addition to volume changes in the material, water evaporation during the drying process causes the substance to shrink [33].

3.5 Comparison of different models of radish drying kinetics

The accuracy of the drying rate predictions concerning the actual data was used

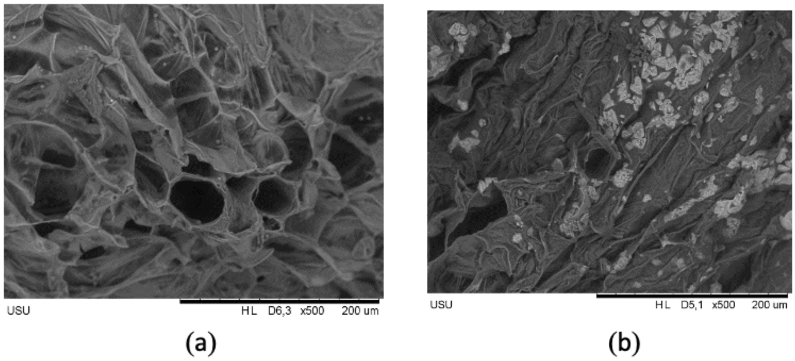


Fig. 6. SEM analysis results of radish (a) Before drying and (b) After drying.

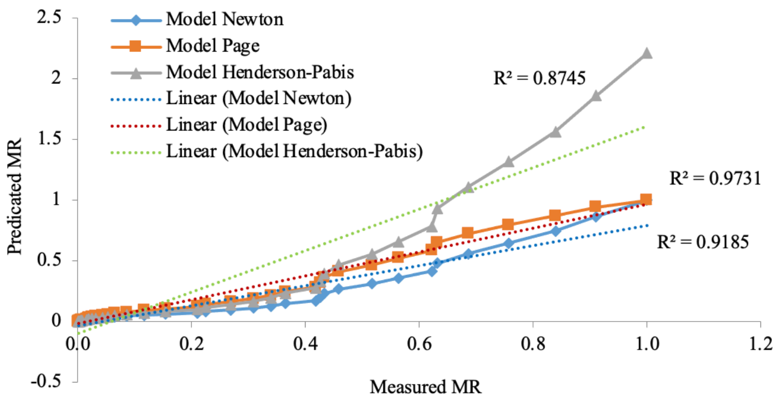
to assess the different kinetic model equations. Each model's kinetic constants determine the equation used to forecast the drying rate. This graph compares each kinetic model's predicted drying rate with the actual data.

Fig. 7 shows the prediction results of various models' outdoor and indoor radish drying rates compared with actual data. Empirical models or statistical analysis can be formulated to explain the basic mechanisms underlying complex systems and thus provide better guidance in the design and control process [34]. The accuracy of different models in forecasting the values of the radish drying rate, as indicated by the proximity of the predicted data on the $y = x$ line, is displayed in Fig. 7.

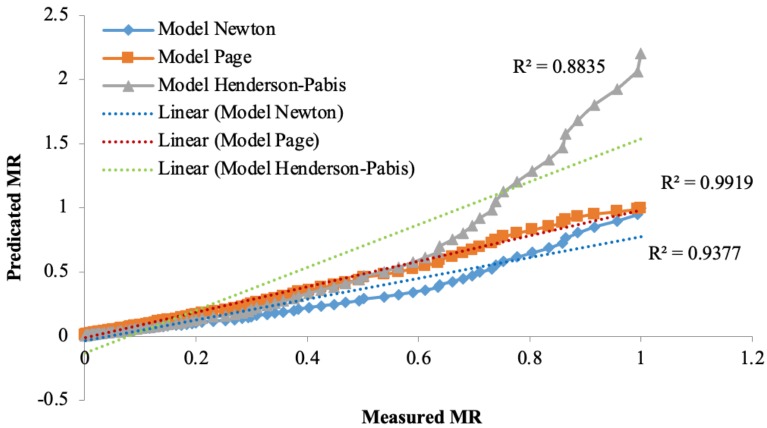
Since the numbers in Fig. 7 are so near the actual data, the radish drying rate predictions made by the Newton, Page, and Henderson-Pabis models are all deemed equally acceptable. With a prediction value of 0.9731 and an accuracy of 97%, the Page model is the best kinetic model for outdoor drying circumstances, and its prediction closely matches the actual data. The Page model, which has a projected value of 0.9919 and an accuracy of 99%, is the best kinetic model whose prediction is closest to the actual data under indoor drying conditions. Previous research has the best coefficient of determination (R^2) acquisition in the page model for rice drying, with an R^2 value of 0.9999 [35], and ginger drying, with an R^2 value of 0.9980 [36].

3.6 Future research direction

This research is about the study of radish drying and the effect of variations in size. After all, it is better to process agricultural products naturally using sunlight because it can maintain better product quality as a primary reference in drying techniques. The drying with sunlight method is more suitable for small or medium-scale businesses. This research can help reduce post-harvest losses, provide information related to the shelf life of radishes, and ensure a better quality of dried products, which is essential. Also, this research could focus on optimizing natural drying techniques by exploring different environmental conditions such as humidity and temperature, and their effects on drying kinetics. Investigations into energy consumption and efficiency of natural drying compared to artificial drying methods could be conducted to develop more sustainable drying practices. Exploring the effects of different pretreatments by blanching on the drying rate and quality of radishes could offer new insights. Future



(a)



(b)

Fig. 7. Comparison of actual data with predicted radish drying rate at various equations of the kinetics model in (a) Outdoor and (b) Indoor.

research could employ advanced mathematical approaches, such as utilizing non-linear regression techniques to develop more accurate drying models that handle complex drying behaviors and interactions between variables. Implementing artificial neural networks to predict drying kinetics based on various input parameters, would provide a robust tool for simulating drying processes. Applying multi-objective optimization techniques to balance different factors such as drying time, energy consumption, and product quality, could help in achieving optimal drying conditions. The real-life importance of this research lies in its potential to enhance food preservation techniques, particularly for small and medium-scale agricultural businesses.

4. Conclusion

Drying of radish was successfully carried out both in indoor and outdoor conditions. The drying of radish in this study was influenced by the size of the material and the drying conditions. The smaller the size of the material, the faster the drying rate. Drying in outdoor conditions is influenced by higher temperatures, so that the higher the temperature, the faster the drying rate. The fastest drying rate occurred outdoors with a material height of 0.5 cm, achieving equilibrium weight in 4 days. The constant weights of samples 1, 2, and 3 outdoors were 0.22 g, 0.37 g, and 0.57 g, respectively, and indoors were 0.25 g, 0.37 g, and 0.54 g. The Page Model best described radish drying, with R^2 values of 0.9731 for outdoor drying and 0.9919 for indoor drying. Drying significantly affected the physical texture and color of the samples.

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