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Optimization of Post-Harvest Preservation of Shallots (Allium ascalonicum L.) through Drying Using Food Dehydrator Technology

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Abstract: Shallots (Allium ascalonicum L.) are a horticultural commodity that is highly susceptible to post-harvest damage due to their high moisture content. One effective method to extend the shelf life of shallots is through drying. This study aims to optimize the drying process of shallots using a food dehydrator at various drying temperatures (40°C, 50°C, and 60°C). The optimization was conducted by evaluating parameters such as moisture content, color, texture, flavonoid content, total phenolic content, and antioxidant activity. In addition, drying characteristics and drying rates, thin-layer drying models, rehydration ratios, and color changes were also analyzed to determine the optimal temperature for the dehydration process. The research methodology involved the following steps: (1) Preparation of materials and equipment, (2) Drying of shallots at 40°C, 50°C, and 60°C and analysis of moisture content, color, texture, flavonoid content, total phenolic content, and antioxidant activity, and (3) Statistical analysis of the data to determine the optimal drying temperature for maintaining shallot quality. The results of this study are expected to provide recommendations for effective drying parameters to maintain post-harvest shallot quality and to improve storage and distribution efficiency.

Keywords: Shallots, Drying, Food Dehydrator, Optimization, Post-harvest.

INTRODUCTION

Allium ascalonicum L., or shallot, is categorized as a strategic horticultural commodity with significant commercial value and a vital role in the daily consumption activities of Indonesians. Shallot consumption ranks second only to chili as a culinary seasoning component, resulting in stable and consistently high market demand throughout the year. Product diversification of shallots extends beyond raw utilization to various processed forms such as concentrates, powders, volatile oils, onion chips, and herbal formulations with potential therapeutic benefits, including cholesterol reduction, blood glucose control, and circulatory system enhancement.

As a strategic horticultural commodity, shallots have great potential for national development and export. Development can be pursued through productivity enhancement, post-harvest processing, and product diversification innovations. This highlights the importance of proper cultivation management and post-harvest handling, including efforts to extend shelf life, in order to increase added value and competitiveness in both domestic and international markets.

Shallots are not only culinary seasonings but also contain significant nutrients essential for human health. They naturally contain minerals such as calcium, phosphorus, iron, magnesium, potassium, zinc, and nitrogen, which support metabolism, bone maintenance, blood formation, and nervous system function. In addition, vitamins including A, C, B1 (thiamine), B2 (riboflavin), B3 (niacin), B6 (pyridoxine), and B9 (folic acid) play critical roles in biochemical activities such as DNA synthesis, erythrocyte formation, and the maintenance of immune and neurological systems.

However, fresh shallots, with water content of 80–85%, are highly perishable and vulnerable to post-harvest deterioration, such as rotting and quality decline during storage and distribution. Therefore, post-harvest processing methods, such as drying, are essential to reduce moisture content, extend shelf life, and maintain product quality.

The implementation of food dehydrators as a solution for optimizing sliced shallot drying can substantially reduce moisture levels while preserving post-harvest quality, including pigmentation, fragrance, and nutrient composition. Compared to traditional methods, this technology demonstrates higher operational efficiency and is optimally applicable for preserving agricultural products at the domestic level and within micro-enterprises.

Food dehydrators allow better temperature control than traditional drying methods such as sun-drying or conventional ovens. Gamma Co-60 irradiation effectively preserves water content and minimizes weight loss, but it is less feasible for small-scale applications. Drying is crucial in post-harvest management to reduce moisture, extend shelf life, and maintain food quality. Temperature is an important factor as it affects nutrients, color, and texture. High temperatures accelerate drying but may degrade bioactive compounds like flavonoids and anthocyanins. Low temperatures preserve nutrients but require longer drying times and increase the risk of microbial contamination and moisture imbalance.

High temperatures accelerate water evaporation but may damage bioactive compounds. Conversely, drying at 40°C retains more nutrients despite requiring longer time compared to 50°C or 60°C. Therefore, optimal drying temperature must balance energy efficiency and sensory quality.

Food dehydrator technology is considered highly efficient as it provides accurate and consistent temperature control throughout the preservation process. The ideal temperature range for shallot drying is between 40°C and 60°C, which has been proven to reduce moisture content without compromising nutritional and organoleptic quality. Based on these considerations, this study aims to optimize the shallot drying process using a food dehydrator at temperatures of 40°C, 50°C, and 60°C to improve product quality and shelf life. Parameters analyzed include moisture content, color transformation, texture characteristics, total flavonoid and phenolic concentration, and antioxidant capacity. The study also measures drying rate, rehydration ratio, and temperature effects on bioactive compound changes, providing practical recommendations for farmers and the shallot processing industry. Data collected through questionnaires from respondents as a sample population will be used to test and evaluate various indicators, dimensions, and factors related to the characteristics and benefits of optimized drying processes in addressing post-harvest preservation challenges.

METHOD

The research took place over a four-month period, beginning in June and ending in September 2025, at the Laboratory of the Faculty of Agriculture, University of Muhammadiyah Malang. The research activities were divided into three main phases: material preparation, implementation of the drying process using food dehydrator technology at varying temperatures of 40°C, 50°C, and 60°C, and laboratory analysis to evaluate the quality parameters of the drying results.

Figures and Tables

This study applied a dual classification of experimental parameters, including controlled constants and manipulative variables. The controlled constants included 1000 grams of whole shallots and shallot slices that had undergone peeling and cleaning with a 3 mm slice thickness. The manipulative parameter was the drying temperature, set at three different levels: 40°C, 50°C, and 60°C. The drying process was implemented using a multi-stage system in a food dehydrator until the water content reached approximately 10%, or a stable mass, in the shallot slices. The drying times were 8, 7, and 4 hours at 40°C, 50°C, and 60°C, respectively.

Figure 1. Initial weight of shallots before peeling and slicing with a weight of 1000 gr.

Figure 2. Sliced shallots to be dried.

Materials and Equipment Used

The main material in this study was shallots from Enrekang Regency, South Sulawesi. For laboratory analysis, chemical reagents such as gallic acid, Folin-Ciocalteu, Na_2CO_3, quercetin, $NaNO_2$, $AlCl_3$, NaOH, DPPH, and p.a. methanol were used. The equipment used included an ARD-PM88 food dehydrator, a digital scale, an oven, desiccators, a UV-Vis spectrophotometer, a centrifuge, a Minolta CR-10 color reader, and other laboratory glassware.


Figure 3. Drying Process with a food dehydrator.

Experimental Procedure

Material Preparation

Shallots were peeled and sliced 3 mm thick. An initial moisture content of 81.057% was obtained by oven drying at 90–100°C until constant weight was achieved, then calculated based on the evaporated mass.

Drying Stage

For each temperature treatment (40°C, 50°C, and 60°C), 1,000 grams of sliced shallots were used. The slices were arranged on a drying rack and then dried with weight monitoring every 10 minutes. After the weight stabilized, the samples were analyzed in the laboratory for phenolic and flavonoid content, antioxidant activity, color, and moisture content.


Figure 4. Minolta CR-10 Color Reader.

Laboratory Analysis

Phenolic Analysis

The procedure for determining phenolic compound content begins with the Folin-Ciocalteu method. The sample is extracted using a p.a. methanol solvent, then mixed with Folin-C reagent and Na_2CO_3, followed by a 120-minute incubation period before absorbance measurements are performed at a wavelength of 765 nm. A calibration curve is generated using a gallic acid standard as a reference. The absorbance values obtained from the phenolic standard solution are then processed using statistical software to generate a simple linear regression equation with the formula $y = a + b(x)$, where the y variable represents the absorbance value and the x variable represents the phenolic concentration. Quantification of the total phenolic content in the sample is achieved by substituting the sample absorbance values into the constructed regression equation, taking into account the sample mass applied and the dilution factors applied throughout the preparation stage.

Flavonoid Analysis

The $AlCl_3$ complexation method was applied to perform flavonoid analysis, where quercetin was used as a reference standard, and absorbance measurements were performed at a wavelength of 420 nm after the extracted sample was mixed with $AlCl_3$ and allowed to stand for 60 minutes [16]. A statistical program was used to process the absorbance data obtained from the flavonoid standard solution to establish a simple linear regression equation in the format y = a + b(x), where y represents the absorbance value and x represents the flavonoid concentration. Quantification of flavonoid levels in the test samples was carried out by substituting the sample absorbance values into the standard regression equation established as a reference, taking into account the sample mass used and the dilution factors that occurred during the preparation stages.

Antioxidant Activity

Antioxidant activity was determined using the DPPH method, in which the sample solution was mixed with DPPH solution, incubated for 30 minutes, and absorbance measured at 516 nm.

Moisture Content Calculation

To calculate moisture content, data is required in the form of the initial (wet) and final (dry) weight of the sample. Moisture content is expressed as a percentage (%) and is calculated based on the difference between the wet and dry weights, then divided by the wet weight and multiplied by 100%. This method refers to the approach described by Nidhi (2015), where moisture content is used as an important parameter to evaluate the level of dryness of a material after the drying process.

$$\text{Mc (wet base)} = \frac{(Mi-Md)}{Mi} \; x \; 100 \qquad (1)$$

$$\text{Mc (dry base)} = \frac{(Mi-Md)}{Md} \; x \; 100 \qquad (2)$$

$$X_n = \frac{W_n - Mbk}{W_n} \times 100\% \qquad (3)$$

Keterangan:
Xn = Water content
Wn = Initial Mass (gram)
Mbk = Dry Basis Mass (gram)

Drying Rate Calculation

To determine the drying rate, data on the sample's weight loss at each time interval during the drying process is required. The drying rate is calculated based on the change in sample weight over time, which reflects the rate of water evaporation from the material during the drying process. This method refers to the approach described by Nindhi (2015), where periodic weight monitoring is the primary basis for analyzing the dynamics of the drying process.

$$DR = \frac{M_i(gram) - M_d(gram)}{t\ (menit)} \qquad (4)$$

Information:
DR = drying rate (gr/s)
Mi = initial mass (gr)
Md = final mass (gr)
T = drying time (minute)

Product Quality Analysis

Chemical Content

Fresh shallots were measured for soluble solids (%), pH, and titratable acidity, expressed in grams of citric acid per liter (g/L). Furthermore, ash and moisture content were analyzed for both fresh and dried shallot samples to compare changes in chemical composition resulting from these treatments.

Bioactive Compounds: Total soluble phenolic content (TSP), flavonoids (F), and antioxidant activity (AA).

Preparation of methanol extracts from fresh and dried shallots was carried out according to the procedure proposed by Siddiq et al. The initial step involved grinding the shallots using a coffee grinder to achieve a uniform consistency. Approximately 5.0 grams of samples, both fresh and dried, were then processed using a sonication extraction technique at a frequency of 40 kHz for 45 minutes at a controlled temperature of 25°C. The sonication process was carried out using an ultrasonic bath (TESTLAB SRL, Buenos Aires, Argentina) using a 20 ml solution of methanol and water at a ratio of 80 (MeOH). The next step involved centrifuging the homogenate at 10,000 g for 10 minutes using a Biofuge 28RS Heraeus Sepatech Centrifuge (Heraeus Instruments, Hanau, Germany), followed by filtration. The extraction procedure was repeated twice for each sample, with the resulting fractions combined and then diluted to a final volume of 40 ml for subsequent analysis.

Total soluble phenolic content (TSP) was determined using the Folin–Ciocalteu method using a linear regression approach from a calibration curve prepared using gallic acid standards. The analysis results were expressed as milligrams of gallic acid equivalents (GAE) per 1000 grams of shallots, both based on fresh weight (fw) (mg GAE/1000 g fw) and dry weight (dw) (mg GAE/1000 g dw). Flavonoid (F) content was analyzed using the $AlCl_3$ complexation method according to a modification of the methodology proposed by Ismail et al. Flavonoid values were calculated from a linear regression of a calibration curve constructed using quercetin as a standard, and the results were expressed as milligrams of quercetin equivalents (QE) per 1000 grams of shallots at both fresh weight (mg QE/1000 g fw) and dry weight (mg QE/1000 g dw).

Antioxidant activity (AA) was evaluated using the Ferric Reducing Antioxidant Power (FRAP) method as described by Oyaizu, with Trolox (0–50 µM) used as the antioxidant standard. The results of the AA measurements of onion extracts were expressed in microMolar Trolox equivalents (µMol TE) per gram of onion based on dry weight (µMol TE/g dw). Furthermore, the free radical scavenging effect was analyzed based on the procedure described by Brand-Williams et al., with some modifications for time efficiency. Quercetin was used as a reference compound, and the EC_{50} value was calculated as the concentration of the extract that provided 50% radical scavenging activity. All measurements were conducted at 25°C using a Multiskan FC spectrometer (Thermo Fisher Scientific Corporation), and each test was performed in triplicate to ensure the validity of the results.

Rehydration Ratio

After the drying process was completed, the rehydration capacity was evaluated to observe potential structural changes resulting from the drying treatment. Rehydration was carried out at room temperature of 25 ± 1°C. The dried samples, consisting of three shallot slices from each drying temperature treatment, were placed in 50 ml of distilled water in a Petri dish and left for 3 hours or until a constant weight was reached. After the rehydration process was completed, the samples were removed from the water and excess water on the surface was removed using a sheet of filter paper. Next, the rehydrated shallot slices were weighed using an electronic scale (Taff-Ware, type I–2000, Max resolution 1000 g, d = 0.1 g). Each treatment was carried out in triplicate, and the obtained values were calculated as an average. The rehydration ratio (RR) was then calculated to assess the water recovery capacity of the samples after the drying process, using the following formula:

$$RR = \frac{Berat\ sampel\ setelah\ rehidrasi\ (gr)}{Berat\ sampel\ sebelum\ rehidrasi\ (gr)}$$

Color Measurement

A Minolta Chroma Meter CR-400 (Minolta Co., Osaka, Japan) was used to evaluate the chromatic characteristics of shallot slices, both during the initial stage and after the drying process was completed. The chromatic measuring instrument was calibrated using a standard white calibration plate before operation, with the illumination setting set to CIE Standard Illuminant C. The CIE Lab* coordinate system was used to record the chromatic values obtained as the average of ten repeated readings. The L* parameter in this coordinate system represents the luminosity intensity with a spectrum of values ranging from 0 (dark) to 1000 (light), while the a* parameter reflects the chromatic gradation from green (negative number) to red (positive number), and the b* parameter describes the chromatic transition from blue (negative number) to yellow (positive number). This chromatic coordinate system has been extensively applied to describe the visual transformations that occur in food as a consequence of processing.

RESULT AND DISCUSSION

Drying Characteristics

The preservation process for thinly sliced shallots using food dehydrator technology was carried out at three temperature variations: 40°C, 50°C, and 60°C, with an initial moisture content of 85%. This drying process lasted for 470 minutes, equivalent to 8 hours, and was terminated when the mass of the shallot slices reached a stable state, indicating equilibrium. The correlation between the drying period and the moisture ratio is illustrated in Figure 5.

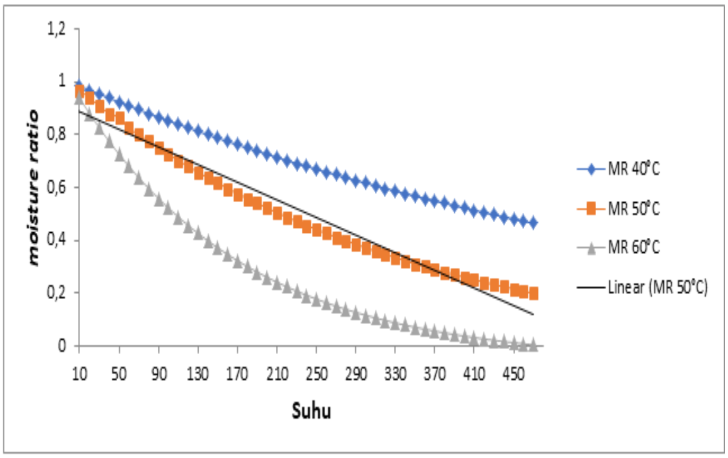

Figure 5. Relationship between drying time and moisture ratio.

Figure 5 shows that the moisture ratio (MR) progressively decreased with the drying time at all temperature variations. This degradation phenomenon reflects the gradual elimination of water content in the shallot pieces, which is directly proportional to the extension of the drying interval. From the applied temperature spectrum, the drying process at 40°C required the longest duration to reach hydration equilibrium (MR reaching zero). In contrast, a temperature of 50°C showed the most expeditious and stable MR degradation. At 60°C, although a substantial decrease was observed in the initial phase, variability occurred at the terminal stage of the drying process.

This decrease in MR values is caused by the migration of water molecules from the interior cells of the shallots to the surrounding atmosphere, a process accelerated by the applied thermal effects. A temperature of 50°C was evaluated as the most optimal condition due to its ability to facilitate a homogeneous drying rate while maintaining the structural integrity of the organic material. These observations correlate with research conducted by Nurul Huda et al. (2020), which stated that applying a temperature of 50°C to the food dehydration procedure effectively optimizes the drying duration while maintaining product quality standards, including achieving an ideal moisture reduction ratio. Increasing the dehydration temperature will generate a more significant thermal gradient between the material and the air medium, thereby intensifying heat energy transfer and accelerating water evaporation (Mitra et al., 2018). However, if the temperature reaches excessive levels, such as 60°C, the structural integrity of the material tissue can degrade, resulting in uneven water transfer distribution (Putri et al., 2021). Based on these considerations, the dehydration temperature needs to be set at an optimal level to maintain process efficiency while not compromising product quality.

Differences in final MR between temperatures are also influenced by slice thickness and initial moisture content. Research by Fatimah et al. (2022) showed that shallots dried at 50°C produced lower final MR values and shorter drying times compared to those dried at 40°C and 60°C. Thus, 50°C can be considered the optimal temperature for drying shallot slices based on the moisture ratio.

The analysis of the drying rate indicates that the drying process of the shallot slices occurs in the falling rate phase. The drying rate itself describes the rate of water evaporation from the material into the air over a specific time period. The drying rate values for shallot slices dried at 40°C, 50°C, and 60°C can be seen in Figure 6.

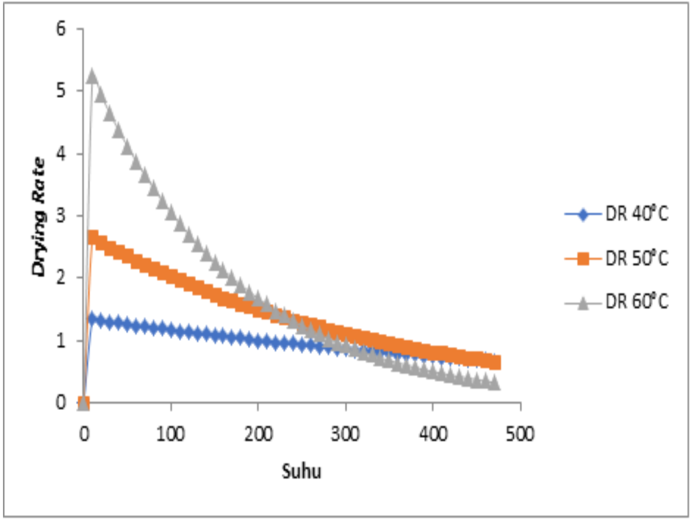

Figure 6. Drying rate curve.

Application of Thin-Layer Drying Models

Predictions of the drying characteristics of shallot slices were made through the implementation of three thin-layer models, aimed at enabling optimization process control to achieve optimal results. Moisture Ratio (MR) data obtained from experimental testing were then adjusted to the Newton, Page, and Henderson & Pabis models. The constant parameters for each model are presented in Table 1.

Table 1. Analysis Results from Thin-Layer Drying Models

Model Pengeringan	**T (^{0}C)**	**k**	**a**	**n**	**R^2**	**RMSE**	**x^2**
Newton	40	0,01			0,913513	0,06	0,04567
	50	0,01			0,913514	0,07	0,04568
	60	0,01			0,913515	0,08	0,04569
Page	40	0,01023		102,952	0,917138	0,01	0,02722
	50	0,01024		102,952	0,917139	0,01	0,02723
	60	0,01025		102,952	0,917140	0,01	0,02724

Henderson - Pabis	40	0,00843	0,25804		0,915501	0,02	0,16874
	50	0,00844	0,25805		0,915502	0,03	0,16875
	60	0,00845	0,25806		0,915503	0,04	0,16876

Table 1 shows the results of the constant parameter analysis of the thin-layer drying model for shallot slices using three mathematical models: Newton, Page, and Henderson & Pabis. Based on the coefficient of determination (R^2), Root Mean Square Error (RMSE), and Chi-Square (χ^2) values, the Page model performed most accurately in describing drying characteristics.

The Page model had the highest R^2 value, ranging from 0.917138 to 0.94040, with the lowest RMSE value between 0.01 and 0.01, and χ^2 values between 0.02722 and 0.02724. This range indicates a high model fit between experimental and predicted values, thus the Page model is considered the most representative in explaining the drying process of shallot slices at temperatures of 40°C, 50°C, and 60°C. This finding is consistent with previous research by Mujumdar et al., 2018, which stated that the Page model is one of the most widely used models and has high accuracy in various food drying processes.

The coefficient of determination (R^2) serves as a parameter describing the capacity of a statistical model to explain the diversity of observed information. An R^2 value close to 1 indicates optimal model fit to the experimental information. Meanwhile, the chi-square (χ^2) is used as an evaluation tool to measure the disparity between model predictions and actual observations. This disparity decreases as the χ^2 value decreases. The Root Mean Square Error (RMSE) parameter also plays a role in representing the magnitude of the deviation of model predictions from actual data. Therefore, a decrease in the RMSE value is positively correlated with an increase in model precision (Sethi et al., 2017; Singh & Heldman, 2020).

The Newton and Henderson & Pabis models had lower R^2 values and higher RMSE and χ^2 than the Page model, so their performance in describing the drying process was not as good as the Page model. Therefore, the Page model was selected as the best model to describe the drying characteristics of shallot slices in this study.

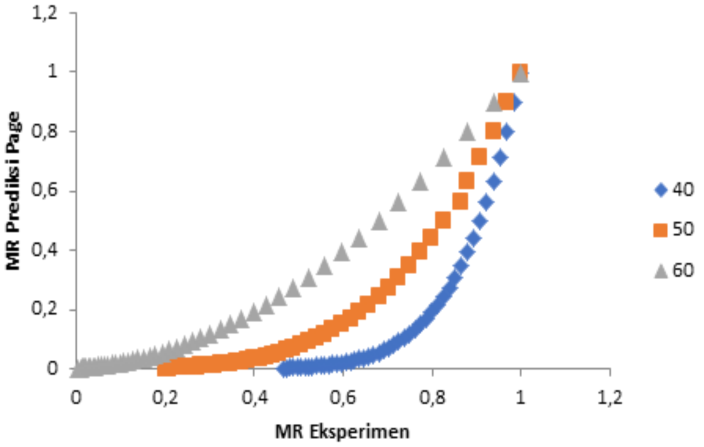

Figure 7. Relationship between predicted and experimental MR using the Page model.

Figure 7 shows a comparison between the predicted Moisture Ratio (MR) and experimental MR values at temperatures of 40°C, 50°C, and 60°C using the Page model. Based on the relationship between the two, the Page model has proven effective in predicting the moisture content of shallot slices at various temperatures, allowing the drying process to be adjusted to achieve optimal results (Santoso et al., 2018).

Most agricultural product drying processes occur in the falling rate phase, where water transfer within the material is dominated by internal diffusion mechanisms. Analysis of this phase is important for understanding drying dynamics, particularly through the calculation of effective diffusivity (Deff) values as a parameter of drying kinetics (Afifah et al., 2017). The Deff values for each treatment can be seen in Table 2.

Table 2. Effective diffusivity (Deff) values for drying shallot slices at various temperatures

Drying Temperature (^{0}C)	Effective Diffusivity (m2/s)
40	1,15 x 10-7
50	1,37 x 10-7
60	6,72 x 10-8

Based on Table 2, the calculated effective diffusivity (Deff) values for the drying process of shallot slices at 40°C, 50°C, and 60°C were 1.14×10^{-7} m²/s, 1.36×10^{-7} m²/s, and 6.72×10^{-8} m²/s, respectively. These values are still within the acceptable range for horticultural products, especially tubers. Increasing the temperature from 40°C to 50°C indicates an increase in the Deff value, indicating accelerated water transfer from within the shallot tissue to the surface of the material. However, at 60°C, the Deff value actually decreased.

This indicates that higher temperatures do not always guarantee greater diffusion efficiency. The decrease in effective diffusivity at 60°C may be due to possible microstructural damage, such as cell collapse or tissue shrinkage, which impedes the passage of water to the surface (Suherman et al., 2020).

Research by Roman et al. (2019) on drying garlic slices also showed that excessive temperature increases can actually reduce drying efficiency due to changes in the material's structure. Meanwhile, differences in Deff between temperatures can also be caused by the initial characteristics of the material, such as water content, slice thickness, and porosity (Afifah et al., 2017). Therefore, a temperature of 50°C in this study can be considered optimal, as it produced the highest Deff value without any indication of decreased efficiency due to material damage.

Rehydration Ratio Analysis

The rehydration ratio is an important indicator in assessing the quality of dried products. This parameter reflects the ability of dried materials to reabsorb water and approach their original state before drying. The effect of varying drying temperatures on the rehydration ratio of shallot slices is shown in Table 3.

Table 3. Rehydration ratio values of dried products at various temperatures

Drying Temperature (^{0}C)	Rehydration Ratio
40	4
50	4,60
60	4,64

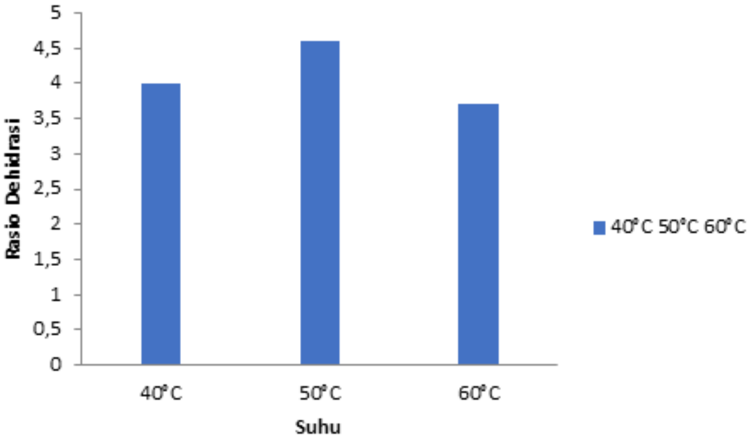

Figure 8. Effect of Drying Temperature on Product Rehydration Ratio

Figure 8 shows the comparison between the mass of shallot slices after rehydration and their dry mass for each drying temperature. The analysis results show that the rehydration ratios at 40°C, 50°C, and 60°C were 4.00; 4.60; and 3.70, respectively. These values indicate that increasing the drying temperature tends to decrease the material's ability to reabsorb water, with the highest temperature resulting in the lowest rehydration ratio.

The decrease in the rehydration ratio at higher temperatures may be attributed to damage to the material's tissue structure due to excessive heat, which causes pores to become narrower and cell walls to become less elastic (Asgar et al., 2013). Shallots themselves are quite sensitive to high temperatures, so drying at 60°C can cause significant structural degradation.

According to Widyasanti et al. (2018), a higher rehydration ratio indicates a better ability of the dried product to return to its original shape. Products with a high rehydration ratio also exhibit better physical quality, as water can optimally re-enter the material's tissues. Therefore, excessively high drying temperatures can actually reduce the rehydration quality of the final product.

Color Analysis

Visual quality, particularly color, plays a crucial role in assessing a product's attractiveness, particularly for food products. Color changes in shallot slices after drying are an important indicator in assessing the impact of temperature treatment on the quality of the final product. Figure 9 presents the results of the analysis of the effect of drying temperature on the color parameters L, a, and b in shallot slices.

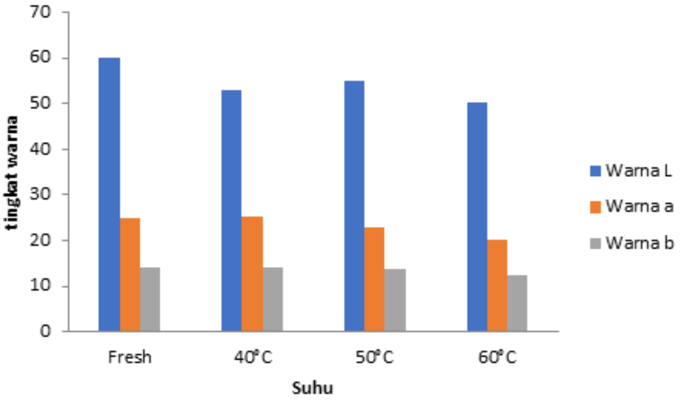

Figure 9. Effect of drying temperature on the L, a, and b values of shallot slices

Based on the research results, drying temperature significantly affected the color changes in shallot slices. The color parameters observed included the L (brightness), a (redness), and b (yellowness) values. These three values tended to decrease with increasing temperature during the drying process.

Freshly sliced shallots had the best color quality, indicated by an L value of 60.25, an a value of 25.14, and a value of 14.00. However, after the drying process, these values gradually decreased. At 40°C, the decrease was still relatively slight, and the product color remained close to its original state. Conversely, at 60°C, the color change was most drastic, resulting in a darker and less visually appealing final product.

A temperature of 50°C produced a fairly balanced color quality. Although the brightness level was not as high as at 40°C, the L, a, and b values were still within the visually acceptable range. Therefore, this temperature is considered an ideal midpoint because it maintains the product's color appearance while speeding up the drying time compared to lower temperatures.

The decrease in the L value is caused by the Maillard reaction, a reaction between reducing sugars and amino acids that forms brown melanoidin compounds. This reaction is more intense at high temperatures, especially in protein-containing foods such as shallots (Nurhayati et al., 2021). The decrease in the a and b values is caused by the degradation of natural pigments, such as anthocyanins and carotenoids, which are very sensitive to heat. Research by Wijaya and Wahyono (2018) also found that increasing the drying temperature and blanching treatment significantly reduced the intensity of red and yellow colors.

Therefore, although 40°C produces the color closest to fresh, 50°C is the optimal temperature for maintaining visual quality with greater drying time efficiency. Meanwhile, 60°C should be avoided if color quality is a primary concern, as it causes significant color degradation.

Flavonoid and Total Phenolic Analysis

Polyphenols are one of the main groups of phytochemical compounds found in shallots. Their structure contains aromatic rings and consists of compounds such as flavonoids and phenols. This study analyzed how varying drying temperatures using a food dehydrator affected the flavonoid and total phenolic levels in shallot slices. The results of these measurements are shown in Figure 10.

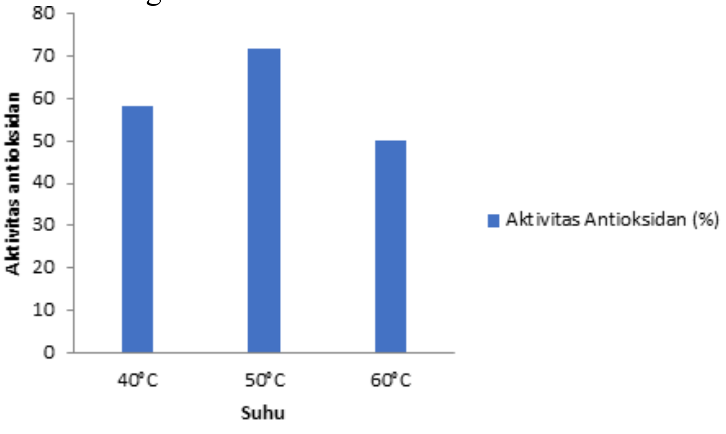

Figure 10. Effect of drying temperature on flavonoids and total phenolics.

This study shows that varying drying temperature significantly impacts the flavonoid and total phenolic content of shallot slices. In general, the levels of both compounds increase as the onions undergo drying from fresh. However, if the drying temperature is too high, the flavonoid and phenolic content actually decreases due to the degradation of active compounds.

Optimal results were obtained at 50°C, where flavonoid and total phenolic content reached 12.5 mg QE/g and 6.8 mg GAE/g, respectively. Conversely, at 40°C, flavonoid and phenolic content were lower, at 10.2 mg QE/g and 5.5 mg GAE/g, respectively. The most drastic decrease occurred at 60°C, with flavonoid values reaching 8.7 mg QE/g and total phenolics at 4.9 mg GAE/g.

The increase in flavonoid and phenolic content from fresh to dried shallots may be due to the inactivation of the polyphenol oxidase enzyme, which typically causes phenolic degradation when the material is still fresh (Khatuliswa et al., 2020). Furthermore, the drying process can also trigger the release of polyphenolic compounds previously bound to cell walls, making them more measurable in laboratory analysis (Roman et al., 2020). According to Lisanti et al. (2015), moderate drying temperatures accelerate the release of bound phenolic compounds through the breakdown of cellular structures.

However, the decrease in bioactive content at 60°C indicates that excessively high temperatures actually cause thermal damage to the polyphenolic compound structure, significantly reducing the flavonoid and phenolic values. This phenomenon has been widely reported in previous studies, which suggest that excessive heating can cause degradation of functional compounds, especially in heat-sensitive horticultural products (Oniya et al., 2021).

Therefore, it can be concluded that drying at 50°C provides the best results in maintaining and even increasing flavonoid and total phenolic content. This temperature is considered optimal because it is high enough to deactivate enzymes that destroy active compounds, but not so extreme that it causes damage to these functional compounds.

Antioxidant Activity Analysis

The results of the study on the effect of drying temperature using a food dehydrator on the antioxidant activity of shallot slices are presented in Figure 11.

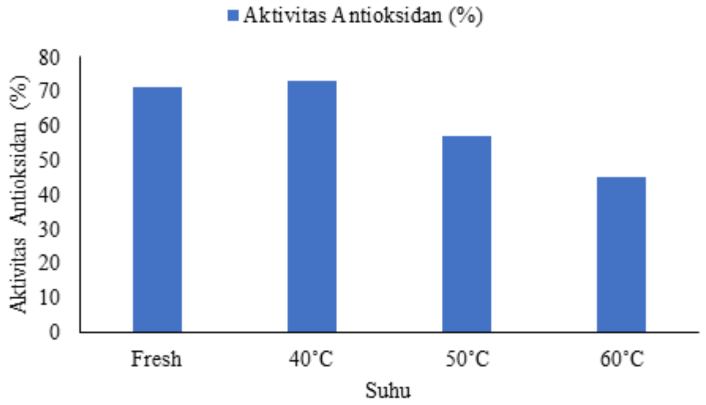

Figure 11. Effect of Drying Temperature on Antioxidant Activity

Based on research findings, temperature variations during the drying process have been shown to significantly impact the transformation of the antioxidant capacity of shallot slices. This antioxidant capacity was evaluated through the material's potential to neutralize free radical molecules, a phenomenon generally strongly correlated with the presence of bioactive components, including polyphenols and flavonoids.

The best results were achieved at 50°C, with an antioxidant activity of 71.5%. Meanwhile, at 40°C, the activity was 58.0%, and the lowest value was recorded at 60°C, at 50.2%. These findings indicate that a moderate drying temperature can optimize the antioxidant capacity of dried shallots.

The increase in antioxidant activity at 50°C can be attributed to the increased content of flavonoids and soluble phenolic compounds resulting from the drying process. As explained by Roman et al. (2020), the drying process can break down cell walls and release previously bound bioactive compounds, thereby increasing the total measured antioxidant activity.

However, when the temperature is increased to 60°C, antioxidant activity decreases significantly. This is due to the degradation of antioxidant compounds due to excessive heat exposure, which can damage the structure of bioactive molecules such as flavonoids and anthocyanins (Yuan et al., 2018). Antioxidant activity is strongly influenced by the stability of the constituent compounds, making stability at the drying temperature crucial.

Therefore, it can be concluded that a drying temperature of 50°C is the optimal temperature for increasing the antioxidant activity of shallot slices. This temperature is high enough to release active compounds from the cell matrix, but not so high as to cause significant damage. Meanwhile, temperatures above 60°C should be avoided due to the risk of reducing the functional benefits of the dried product.

CONCLUSION

Based on the research results, drying temperature significantly affects the quality of shallot slices. Among the temperatures of 40°C, 50°C, and 60°C, 50°C proved to be the most optimal. At this temperature, the decrease in Moisture Ratio and drying rate occurred efficiently without damaging the material structure. The Page model most accurately describes the drying process. A temperature of 50°C also produced the highest effective diffusivity value, the best rehydration ratio, as well as the best color, flavonoid content, phenolic, and antioxidant activity. Conversely, a temperature of 60°C caused structural damage that reduced product quality. Therefore, a temperature of 50°C is recommended as the best temperature for drying shallot slices.

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