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THE INFLUENCE OF THE DRYING CONDITIONS ON CHANGES IN PHYSICAL AND CHEMICAL PROPERTIES OF *ETLINGERA ELATIOR* (EE)

Etlingera elatior (EE), commonly known as torch lily, wild ginger, and *Bunga Kantan* in Malaysia, is a versatile plant from the *Zingiberaceae* family, valued both for its ornamental blossoms and culinary uses. Infrared (IR) drying has emerged as a promising technique due to its superior drying efficiency and potential to preserve the quality of plant materials by minimizing shrinkage and maintaining material integrity. This study investigates the effects of two drying methods; IR drying and oven (OD) drying on the material characteristics of EE, specifically focusing on drying kinetics, color, shrinkage, and antioxidant capacity. EE samples were dried at temperatures ranging from 50 to 80°C until they reached a constant weight. The findings indicate that IR drying achieves a faster drying time and higher drying rate compared to OD drying. The total color change (ΔE) was lower for OD drying, with a value of 18.96, compared to 23.40 for IR drying. Regarding shrinkage, IR drying resulted in the smallest shrinkage (124.91), while OD drying showed slightly higher shrinkage (132.41). These results suggest that IR drying at 80°C is a favorable method for preserving the material characteristics of *Etlingera elatior*.

Keyword: Etlingera Elatior; Bunga Kantan; Infrared Drying; Drying Kinetics; physicochemical

1. Introduction

Etlingera elatior (EE), commonly known as *Bunga Kantan* in Malaysia, is a prominent member of the Zingiberaceae family, widely cultivated for both ornamental and culinary purposes. This plant, also referred to as torch ginger, torch lily, wild ginger, or Philippine wax flower, is especially valued as a spice in traditional Malaysian and South East Asia (SEA) cuisines [1]. The torch ginger inflorescence comes in three distinct colors: red, pink, and white. While the red and white varieties are relatively rare, the pink variety is more commonly found, particularly in rural areas and along the edges of jungles. The plant's versatility and vibrant appearance make it a significant cultural and agricultural asset in the regions where it is grown.

Due to its vibrant red color, distinctive flavor, and ability to enhance the taste of various dishes, the inflorescence and flowers of EE are frequently used as key ingredients in traditional cuisines. The consumption of EE is considered highly nutritious, as it is rich in unsaturated fatty acids, proteins, amino acids, and essential minerals. Notably, it is also known for its low levels of heavy metal contamination [2]. The dried flowers of EE contain approximately 12.6% protein, 18.2% fat, and 17% fiber [3]. The plant's high fiber content is particularly beneficial, as it may help reduce blood cholesterol levels, lower blood pressure, decrease the risk of heart disease, and alleviate constipation.

As the demand for flavorful and aromatic food products continues to rise, plants and spices play a crucial role in seasoning and preserving food. Drying is a widely used technique to reduce moisture content, thereby inhibiting microbial growth in fresh plants and extending the shelf life of EE and other botanicals, while preserving essential qualities such as taste, aroma, and color [4]. The effectiveness of the drying process is influenced by several factors, including drying temperature, duration, and the type of drying equipment used, all of which can impact the retention of bioactive components and the preservation of color. The oven drying method and infrared drying method, in particular, demonstrate distinct differences in their operational mechanisms and efficiencies, making them critical considerations for various industrial applications.

Oven drying is a traditional method commonly used for drying agricultural products. It relies on convection to transfer heat from the air to the material being dried, leading to a gradual

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removal of moisture. This conventional technique is often associated with slower drying rates, high energy consumption, and the potential for uneven drying, which can result in the degradation of heat-sensitive compounds [5]. Additionally, the prolonged exposure to heat in oven drying can lead to the loss of volatile flavors and essential nutrients, thereby compromising the overall quality of the dried product.

Infrared drying is emerging as a promising technique for food dehydration. This method utilizes electromagnetic radiation from the infrared (IR) spectrum, which is absorbed by the material's surface based on its absorptivity [6]. Infrared radiation directly transfers energy to the material, causing water molecules to vibrate and evaporate at a significantly faster rate [7]. This accelerated drying process not only enhances energy efficiency but also helps preserve the quality and nutritional properties of the dried material. Moreover, the precise temperature control inherent in infrared drying minimizes the risk of thermal damage, making it particularly advantageous for drying sensitive materials such as fruits and pharmaceuticals [8].

Preserving the quality of agricultural products, particularly EE, over long periods is a significant challenge. Previous studies have shown that EE tends to lose its aroma and characteristic properties when exposed to external environmental conditions. This raises concerns about how to effectively preserve EE without compromising its quality. Infrared (IR) drying technology, with its increased radiation frequency and penetration power, particularly in the short and medium-wave infrared range (0.75-4 μm) [7], has been identified as a potentially superior method for drying agricultural products. Compared to conventional drying methods, IR drying offers several advantages, including greater energy efficiency, faster drying times, uniform heating, precise temperature control, improved end product quality, and lower energy costs. Therefore, this research investigates the potential of IR and oven drying methods in preserving EE. The objective of this study is to evaluate the effects of these different drying methods on the drying kinetics and physicochemical properties of EE, such as color, shrinkage, and antioxidant activity.

2. Experiment

2.1. Materials

Etlingera elatior (EE) was obtained from a local supermarket in Shah Alam, Selangor, and immediately stored in a refrigerator at 4°C±1°C to preserve its freshness. Only high-quality, fresh EE specimens were carefully selected for the experiment to ensure the reliability of the results. The chemicals used in this study included distilled water, methanol, and 2,2-diphenyl-1-picrylhydrazyl (DPPH), which were employed in the preparation and analysis of the samples. Distilled water was used for cleaning and preparing the plant materials, while methanol served as a solvent in the extraction processes. DPPH was utilized in the antioxidant assays to assess the free radical scavenging activity of the EE extracts, providing insights into the antioxidant properties retained after the drying processes.

2.2. Preparation of sample for drying experiment

For the experiment, fresh EE petals displaying optimal structure and appearance were selected. These petals were carefully removed from the stalks and thoroughly washed to eliminate any impurities. To ensure uniformity in the drying process, the petals were cut into evenly sized, rectangular pieces. The drying process was carried out using two methods: oven drying with a Memmert oven and a custom-designed infrared (IR) dryer. Each drying test was performed with five replicates at four different temperatures: 50°C, 60°C, 70°C, and 80°C [9]. The weight of the samples was measured at 10-minute intervals until they reached a stable weight. The data collected was then used to determine the average moisture content and to plot drying curves, which illustrate the drying behavior of the EE petals under various conditions.

2.3. Moisture Ratio Analysis

The moisture ratio, also referred to as the moisture content ratio, is a measure of the amount of moisture present in a material relative to its initial or equilibrium moisture content. The moisture content (MC) is calculated using the following equation (Eq. (1)).

$$MC = \frac{(w-d)}{d \times 100} \tag{1}$$

where, w is the weight while wet and d is the weight while dry.

The moisture ratios (MR) of the EE were calculated using the following Eq. (2) [10]:

$$M_R = \frac{M_t}{M_0} \tag{2}$$

where, M_t is the moisture content at a drying time t, kg/kg (dry basis); and M_0 is the initial moisture content. This calculation provides a dimensionless ratio that reflects the relative moisture content of the material as drying progresses. By plotting the moisture ratio against drying time, drying curves were generated to visually represent the drying kinetics of EE under different conditions. These curves are instrumental in analyzing and comparing the efficiency and effectiveness of the drying methods used in the study.

2.4. Drying Rate (DR)

The drying rate (DR) quantifies the speed at which moisture is removed from the EE material during the drying process.

It indicates the rate of moisture loss per unit of time, providing valuable insights into the efficiency of the drying method used. The drying rate was calculated using Eq. (3):

$$DR = \frac{M_{t1} - M_{t2}}{t_1 - t_2} \quad (3)$$

where, and DR are the drying times, (h); and M_{t1} and M_{t2} are the moisture contents, kg/kg (dry basis, d.b.) at times t_1 and t_2, respectively. This calculation helps in determining how quickly moisture is being removed at different stages of the drying process, allowing for a detailed analysis of the drying kinetics under various conditions.

2.5. Mathematical modelling of drying curves

Mathematical modeling of the drying process was conducted using Microsoft Excel Solver® and nonlinear regression analysis. The experimental moisture ratio (MR) data was compared with the predicted MR values obtained from four established thin-layer drying models, as outlined in TABLE 1. The best-fit mathematical model was determined based on statistical evaluation criteria, including the highest correlation coefficient (R^2) (Eq. (4)) and the lowest values of root mean square error (RMSE) (Eq. (5)) and chi-squared (χ^2) (Eq. [6]) [11]. These criteria provided a robust assessment of the model's accuracy in predicting the drying behavior of EE.

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (MR_{pre,i} - MR_{\exp,i})^2}{\sum_{i=1}^{n} (\overline{MR_{pre}} - MR_{\exp,i})^2} \quad (4)$$

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{1}{N} \left[\left(MR_{\exp,i} - MR_{pre,i} \right)^2 \right]} \quad (5)$$

$$x^2 = \sum_{i=1}^{n} \frac{\left(MR_{\exp,i} - MR_{pre,i} \right)^2}{N - n} \quad (6)$$

where, $MR_{\exp,i}$ and $MR_{pre,i}$ are the experimental and predicted moisture ratio, MR_{pre} is the average of predicted moisture ratio, N is the number of observations and n is the number of constants.

TABLE 1

Thin Layer Mathematical Model Equations

Model	Equation	Reference
Modified Page	$MR = \exp[-(kt)^n]$	[12]
Midili & Kucuk	$MR = a\exp(-kt)^n + bt$	[12]
Lewis	$MR = \exp(-kt)$	[13]
Henderson & Pabis	$MR = a\exp(-kt)$	[14]
Page	$MR = \exp(-kt^n)$	[14]

where k,a,b and n are constants

2.6. Physical Properties of *Etlingera elatior* (EE)

The shrinkage of EE petals, referred to as dimensional shrinkage, was calculated for each size, plant species, sampling site, and moisture content level using the following equation (Eq. 7):

$$Shrinkage(\%) = \frac{size\ difference}{intial\ size} \times 100 \quad (7)$$

Total shrinkage was determined by summing the three-dimensional shrinkages – length, width, and thickness – for each petal. These measurements were performed using a digital electronic calliper to ensure precise and accurate data [15].

2.7. Color Analysis

The color of EE petals was measured before and after drying using a colorimeter (CR-400, Konica Minolta Sensing, Japan). The color was expressed in CIELAB coordinates: L^* (lightness), a^* (redness or greenness), and b^* (yellowness or blueness), with a standard D65 illuminant. The total color change (ΔE) between the fresh and dried samples was calculated using Eq. (8) [16].

$$\Delta E = \sqrt{\left(L^* - L_0^*\right) + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (8)$$

where, ΔE is the difference between the colour of the fresh and dried EE samples; L_0^*, a_0^*, and b_0^* are the color parameters of the initial colour; and L^*, a^*, and b^* are the colour parameters of the dried samples. This calculation provides a quantitative assessment of the color variation resulting from the drying process.

2.8. Antioxidant Analysis

The antioxidant analysis begun with the extraction by treating 1 g of the powdered EE sample with 25 mL of 99% methanol. The mixture was incubated for two hours at 50°C in a shaking water bath [17]. After incubation, the extracts were centrifuged for 15 minutes at 5000 rpm. The resulting filtered residue was then dissolved in 99% methanol to reach a final volume of 100 mL. This solution was sealed and stored at 4°C until further use.

A 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution was prepared by dissolving 4 mg of DPPH in 99% methanol. To preserve its stability, the DPPH solution was stored in a cool, dark environment [18]. The prepared extracts were used to evaluate the antioxidant capacity through the DPPH radical scavenging method. Specifically, 2 mL of DPPH solution was mixed with 2 mL of the sample extract in a test tube, followed by a 30-minute incubation period in the dark. The absorbance was measured at 517 nm using a UV–visible spectrophotometer. The inhibition percentage of the DPPH free radical for each concentration of EE solution was calculated using the following equation (Eq. 9).

$$Inhibition\left(\%\right) = \frac{Abs_{t=0\ \mathrm{min}} - Abs_{t=30\ \mathrm{min}}}{Abs_{t=0\ \mathrm{min}} \times 100\%} \tag{9}$$

where $Abs_{t=0\ \mathrm{min}}$ and $Abs_{t=30\ \mathrm{min}}$ represent the absorbance of the mixture of extract and DPPH at time zero and after 30 min of incubation, respectively.

3. Results and discussion

3.1. Moisture Ratio Analysis

The drying behavior of EE under different drying techniques, specifically oven drying (OD) and infrared (IR) drying, is depicted in Figs. 1 and 2. These figures highlight the distinct impact of each method on the drying curves of EE. As expected, the drying time required to reduce the moisture content of EE decreased with increasing drying temperatures, a trend observed across both drying techniques. This reduction in drying time is crucial, as it reflects the efficiency of the drying process, which is a key factor in industrial applications where time and energy consumption are critical considerations.

In the case of OD drying, the drying time decreased markedly from 880 minutes at 50°C to 210 minutes at 80°C. Similarly, IR drying showed an even more pronounced decrease in drying time, with a reduction from 130 minutes at 50°C to just 50 minutes at 80°C. These results demonstrate that elevated drying temperatures provide a greater thermodynamic driving force for heat and mass transfer, thereby significantly enhancing the drying kinetics of EE [19]. Moreover, both OD and IR drying techniques required less drying time as the temperature increased. This can be attributed to the higher temperature difference between the air and the product, which enhances the air's capacity to absorb moisture. As the temperature rises, the product heats up more quickly, water evaporates more efficiently, and overall drying time is reduced [20].

Similar findings have been observed in previous studies with other therapeutic herbs such as mint, thyme, and peppermint leaves [21-23] respectively. Based on the data presented in the figures, it is evident that in terms of drying time and drying rate, the optimal temperature for drying EE is 80°C, as it offers the shortest drying times, and the highest drying rate compared to other temperatures. This can be explained by the fact that infrared energy penetrates a limited depth of the product, converting it into thermal energy [25]. As a result, the water transfer process becomes more intense in IR drying compared to oven drying, leading to a more efficient drying process.

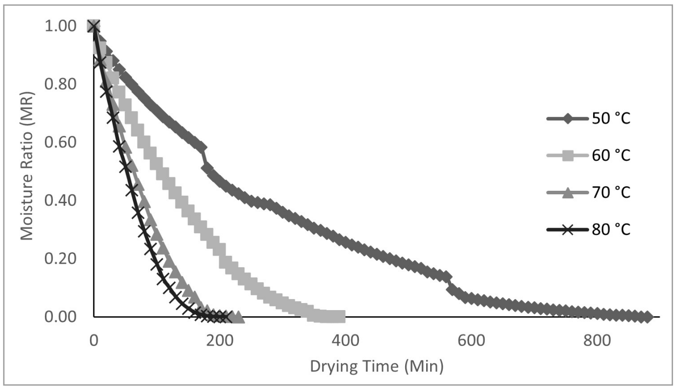

Fig. 1. Moisture Ratio of Dried EE at Different Temperatures undergoes Oven Drying

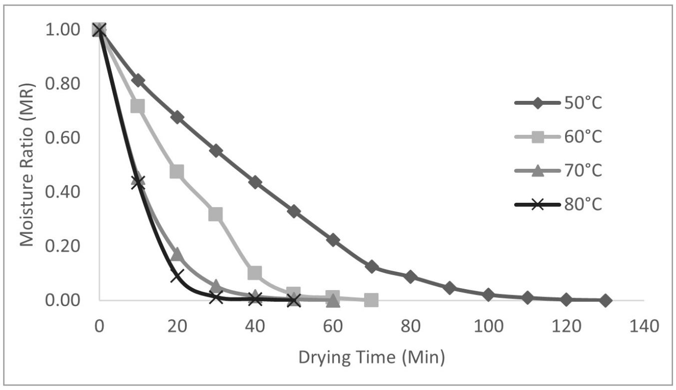

Fig. 2. Moisture Ratio of Dried EE undergoes IR Drying at Different Temperatures

3.2. Drying Rate

Figs. 3 and 4 illustrate the correlation between the drying rate and moisture content of EE under oven drying (OD) and infrared (IR) drying techniques. The observed trend shows a consistent decrease in the drying rate as the moisture content decreases, which is a typical characteristic of the falling-rate period. This indicates that the drying process of EE is predominantly governed by the internal diffusion of moisture, as supported by previous studies [26]. Additionally, a positive correlation between drying rates and increasing temperatures was observed. This phenomenon can be attributed to the elevated vapor pressure of water within the product, which is intensified by higher drying temperatures, thereby facilitating faster moisture removal.

During IR drying, the absorption of infrared radiation rapidly generates heat both at the surface and within the inner layers of the EE sample, significantly enhancing the rate of water removal compared to OD drying. This efficient energy transfer not only accelerates the drying process but also makes IR drying a more energy-efficient method [27]. The higher drying rates observed at 80°C in IR drying, particularly emphasize its effectiveness, as the drying time is drastically reduced compared to OD drying. This reduction in drying time not only enhances efficiency but also suggests lower energy consumption, making IR drying a more sustainable option for industrial applications.

Moreover, the increased efficiency of IR drying, particularly in terms of its faster drying rates, offers substantial benefits for maintaining the quality of EE. By reducing the exposure time to heat, IR drying helps in preserving the bioactive compounds and sensory properties of EE, which are crucial for its use in various food and pharmaceutical applications. This makes IR drying a preferable method over OD drying, especially when the goal is to maintain the integrity of sensitive materials like EE.

The comparative analysis indicates that while both OD and IR drying methods are effective in reducing the moisture content of EE, IR drying clearly better than OD drying in terms of drying rate, energy efficiency, and preservation of product quality. The enhanced drying kinetics observed in IR drying, particularly at higher temperatures, make it the preferred method for drying EE, balancing the need for rapid moisture removal with the preservation of essential qualities.

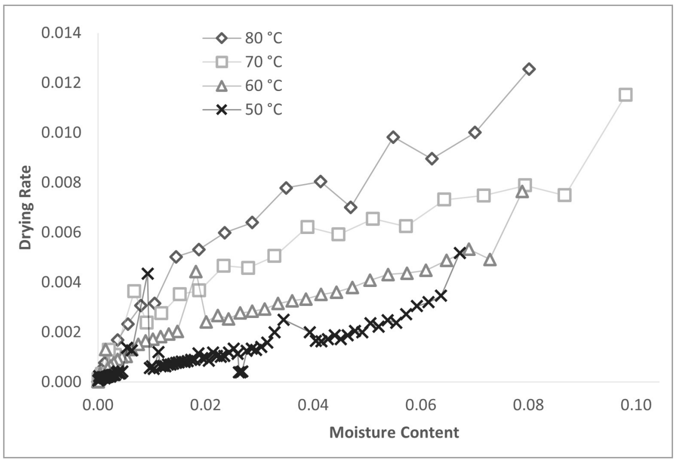

Fig. 3. Drying Rate of EE Versus Moisture Content at Different Temperatures in Oven Drying

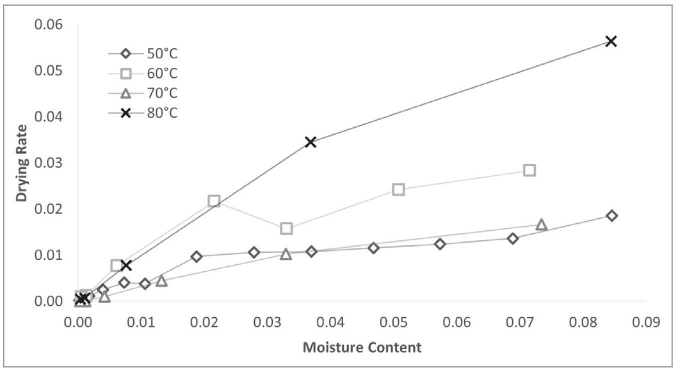

Fig. 4. Drying Rate of EE Versus Moisture Content at Different Temperatures in IR Drying

3.3. Mathematical modelling of drying curves

Nonlinear regression analysis was conducted to examine the drying behavior of Etlingera elatior (EE) using both infrared (IR) drying and oven drying (OD) techniques. The selection of the most appropriate mathematical model to represent the drying kinetics was based on criteria such as the maximum correlation coefficient (R^2) and the minimum values of root mean square error (RMSE) and chi-squared (χ^2). The statistical analysis of the drying models, as presented in TABLE 2, identified Midilli's model as the best fit for both IR and OD drying techniques.

Midilli's model demonstrated the highest R^2 value, along with the lowest χ^2 and RMSE values among the dynamic models

TABLE 2

Mathematical Model Analysis for Drying of *Etlingera Elatior*

Type of drying	Temperature (°C)	Evaluation Criteria	Modified Page	Midilli	Lewis	Henderson	Page
Infrared-drying	50	R^2	0.999538	0.999511	0.997652	0.997973	0.999464
		χ^2	0.000663	0.000606	0.002901	0.002498	0.000663
		RMSE	0.024816	0.023714	0.051905	0.048166	0.024816
	60	R^2	0.998557	0.998591	0.994275	0.994742	0.998557
		χ^2	0.001091	0.001067	0.004320	0.003946	0.001091
		RMSE	0.030899	0.030550	0.061483	0.058759	0.030899
	70	R^2	0.999982	0.999690	0.999103	0.999129	0.999982
		χ^2	0.000006	0.000109	0.000314	0.000304	0.000006
		RMSE	0.002312	0.009660	0.016398	0.016147	0.002312
	80	R^2	0.999991	0.999995	0.995022	0.994675	0.999991
		χ^2	0.000003	0.000002	0.001624	0.001593	0.000003
		RMSE	0.001544	0.001203	0.036784	0.036429	0.001544
Oven-drying	50	R^2	0.999895	0.999912	0.999867	0.999870	0.999895
		χ^2	0.000795	0.000671	0.001013	0.000991	0.000795
		RMSE	0.028044	0.025762	0.031642	0.031309	0.028044
	60	R^2	0.999829	0.999885	0.999474	0.999555	0.999829
		χ^2	0.000691	0.000466	0.002123	0.001794	0.000691
		RMSE	0.025963	0.021312	0.045492	0.041827	0.025963
	70	R^2	0.999715	0.999795	0.998821	0.999022	0.999715
		χ^2	0.000652	0.000471	0.002703	0.002239	0.000652
		RMSE	0.025002	0.021242	0.050894	0.046317	0.025002
	80	R^2	0.999749	0.999808	0.998650	0.998906	0.999749
		χ^2	0.000436	0.000335	0.002351	0.001902	0.000436
		RMSE	0.020409	0.017886	0.047373	0.042607	0.020409

evaluated. This indicates that Midilli's model provides the most accurate prediction of the drying characteristics of EE. The model's suitability is further supported by its ability to predict moisture content (MC) in a manner that closely aligns with the experimental moisture ratio values, exhibiting a strong linear relationship. This finding is consistent with previous studies, such as those on dried mint leaves using infrared and hot air methods [28], where Midilli's model also proved to be the most accurate.

Researchers have observed that the drying speed of products tends to decrease over time, a behavior well-captured by Midilli's model, making it an ideal choice for representing the drying kinetics in IR drying scenarios. Similar conclusions were drawn in separate studies, including one on the infrared drying of okra pods [12] and another on the OD drying of lemon peels [29], where Midilli's model provided more accurate predictions compared to other models. These consistent findings across different studies highlight the robustness and versatility of Midilli's model in accurately representing the drying kinetics of various agricultural products under different drying conditions.

4. Physical Properties of *Etlingera Elatior* (EE)

4.1. Shrinkage

The effect of the drying method on the shrinkage of EE is illustrated in Fig. 5. The total shrinkage observed was 105.66%, 136.04%, 138.43%, and 132.41% for oven drying, and 154.03%, 141.02%, 142.00%, and 124.91% for infrared (IR) drying at temperatures of 50°C, 60°C, 70°C, and 80°C, respectively. These results indicate that oven drying generally resulted in smaller overall shrinkage compared to IR drying, particularly at higher temperatures.

The smaller shrinkage observed in oven drying can be attributed to the longer drying times associated with this method, which allows the product to shrink more gradually. This slower rate of moisture loss provides the material with more time to adjust structurally, resulting in less pronounced shrinkage. Conversely, IR drying, which operates at a higher energy intensity, induces rapid water removal from the sample's tissues. This accelerated drying process leads to faster and more significant shrinkage, as the material does not have as much time to adapt to the moisture loss [30].

The extensive heat generated during IR drying not only enhances the drying rate but also contributes to the structural changes in the material. This is particularly evident at lower temperatures, where IR drying still results in greater shrinkage compared to oven drying. At 80°C, however, the shrinkage for IR drying is lower than at other temperatures, suggesting that the rapid drying process at this temperature may help in maintaining more of the material's structural integrity by quickly locking in its shape before extensive shrinkage can occur.

These findings suggest that while IR drying is more efficient in terms of time and energy, it may also lead to greater dimensional changes in the material, which could be a consideration depending on the intended use of the dried product. The choice between oven drying and IR drying should therefore balance the need for drying efficiency with the desired physical properties of the final product.

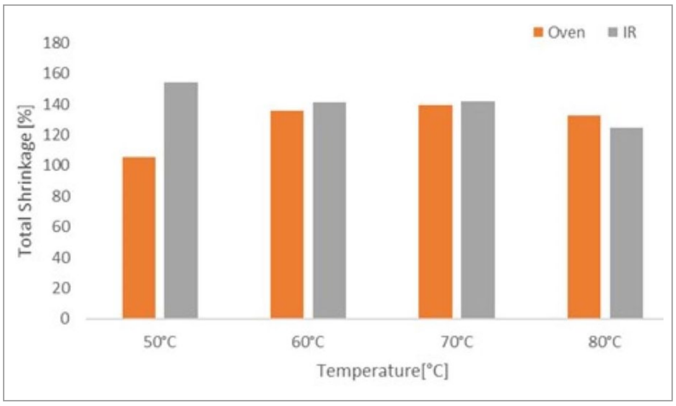

Fig. 5. Comparison of Total Shrinkage of Dried EE in Oven and IR Drying

4.2. Colour Measurement

Colour is a critical aspect of food quality that significantly influences consumer preferences and perceptions. The total colour changes of EE following drying is summarized in TABLE 3. The colour parameters, specifically L^* (lightness), a^* (redness or greenness), and b^* (yellowness or blueness), provide

TABLE 3

Colour Changes of Dried EE under Different Drying Techniques and Temperatures

Temperature	Drying Method	L^*	a^*	b^*	ΔE
	Fresh	66.37±7.54	28.20±5.63	20.68±2.46	—
50°C	Oven	58.25±6.96	11.92±6.63	7.34±2.68	17.84±8.80
	IR	50.32±4.50	12.66±12.42	2.87±3.15	22.63±11.23
60°C	Oven	46.32±4.93	20.85±5.78	3.38±2.38	16.15±4.70
	IR	44.80±7.61	15.28±5.26	2.81±2.71	18.06±9.14
70°C	Oven	69.76±9.98	8.49±4.75	2.70±0.75	31.07±7.40
	IR	43.26±9.27	15.03±7.48	5.66±5.14	17.98±8.02
80°C	Oven	50.21±5.39	19.72±6.64	3.81±1.68	18.96±6.07
	IR	42.47±7.76	9.36±5.67	10.08±9.70	23.40±12.11

a comprehensive measure of how the drying process affects the appearance of the dried product. While a^* and b^* values typically exhibited minor variations, a consistent decrease in L^* values was observed as the drying temperatures increased, indicating a reduction in lightness. Positive a^* values indicate redness, whereas negative a^* values suggest greenness. Similarly, positive b^* values correspond to yellowness, and negative b^* values to blueness [31].

The total colour changes were found to be significantly different between the IR drying and OD drying methods. Notably, the lightness (L^*) of the dried EE decreased with rising drying temperatures, which can be attributed to the Maillard reaction – a non-enzymatic browning process that occurs during drying, transforming red pigments into darker pigments. This reaction intensifies with higher temperatures, leading to a more pronounced darkening of the dried samples [32]. This trend aligns with previous studies, such as those on rose petals, where an increase in IR drying temperature resulted in a decrease in colour intensity and drying time [33]. The observed colour changes in EE highlight the importance of controlling drying conditions to preserve the visual appeal of dried products, as excessive darkening could negatively impact consumer acceptance.

5. Chemical Properties of *Etlingera elatior* (EE)

5.1. Analysis of Antioxidant

Fig. 6 illustrates the comparison of DPPH % inhibition, which measures the antioxidant capacity of EE, across different drying methods. The fresh EE sample exhibits the highest DPPH % inhibition, indicating the strongest antioxidant activity and suggesting that the bioactive compounds responsible for scavenging free radicals are most potent in their natural state. A higher percentage of DPPH inhibition in antioxidant analysis indicates a stronger antioxidant activity of the tested substance [34]. However, a significant reduction in antioxidant capacity is observed following the drying process, irrespective of the method used. After oven drying, the antioxidant capacity decreases considerably, likely due to the prolonged heat exposure that leads to the oxidation and degradation of sensitive phytochemicals. Infrared drying similarly results in a reduced DPPH % inhibition, indicating that despite its efficiency in terms of drying time and energy consumption, it still compromises the antioxidant potential of EE to a similar degree as oven drying.

The reduction of antioxidant capacity from fresh to dried is partially related to the duration time and drying temperature, both long time and high temperature enhance the oxidation and degradation of phytochemicals with antioxidant potential [35]. This data highlights the trade-off between extending the shelf life of EE through drying and maintaining its antioxidant properties. Both drying methods, while effective for moisture removal, lead to a noticeable decrease in antioxidant capacity. In other words, a higher percentage of DPPH inhibition suggests a more potent antioxidant effect, indicating its potential for providing protection against oxidative stress and related health benefits [36]. To better preserve the health benefits associated with EE's antioxidant compounds, it is essential to optimize drying parameters, such as minimizing exposure time and controlling drying temperature, to retain a higher percentage of these beneficial compounds in the dried product.

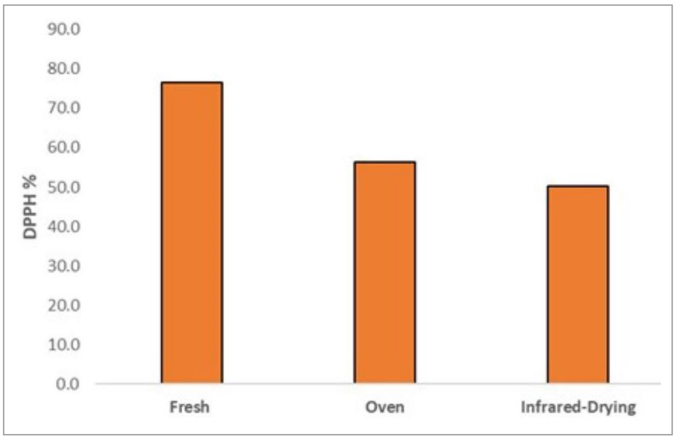

Fig. 6. Comparison of DPPH Inhibition Percentage of EE

6. Conclusion

This work demonstrated that Etlingera elatior (EE) could be effectively dried using both infrared (IR) and oven drying methods. The study found that as the product's moisture content decreased, the rate of evaporation gradually reduced, a common characteristic observed in drying processes. Midilli's model was identified as the most suitable dynamic model for predicting the drying behavior of EE across both drying methods, with high R^2 values ranging from 0.9886 to 0.999795, the lowest chi-squared (χ^2) values ranging from 0.000002 to 0.001067, and the lowest root mean square error (RMSE) values between 0.001203 and 0.030550. Additionally, the results indicated that IR drying, particularly at 80°C, resulted in less overall shrinkage compared to oven drying, making it a more suitable method for preserving the structural integrity of EE. Based on the findings, the highest quality of dried EE was achieved using the IR drying method at 80°C, due to its shorter drying time, higher drying rate, and lower shrinkage value. Future research on the investigation of EE shelf life especially on the nutritional, sensory analysis and microbiology stability would be beneficial for sustaining the EE in agricultural and food industries.

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