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Hot Air Drying of Brazilian Spinach Leaves

Norawanis Abdul Razak[1*], Lim Teik Wei[1], Lee Yit Leng[2] and Sriyana Abdullah[2]

[1]Faculty of Mechanical Engineering & Technology, Universiti Malaysia Perlis, Kampus Tetap Pauh Putra, 02600 Arau, Perlis, Malaysia
[2]Faculty of Chemical Engineering & Technology, Universiti Malaysia Perlis, Kampus Tetap Pauh Putra, 02600 Arau, Perlis, Malaysia

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ABSTRACT

Brazilian spinach is one of the best leafy vegetables with tons of nutrients and has a range of health benefits. Its quality also determines the acceptance of customers to buy and consume it. The common method to extend the shelf life of the spinach is through drying treatment and preserving the color and texture quality of the leaves. Therefore, this study aimed to determine the drying characteristics of Brazilian spinach and investigate the effect of drying temperature on the color and texture quality of Brazilian spinach. Brazilian spinach leaves were dried using a hot air dryer under different temperatures (30, 50, 70 and 90 ℃). Results showed that the drying rate increased when temperature increased. It was found that the Midili model gave the best fitting to the experimental moisture ratio for a specific drying treatment. Drying the Brazilian spinach leaves at 50 ℃ was the best condition for preserving their color and texture properties.

Keywords: Brazilian spinach leaves, Drying characteristic and Hot air drying

1. INTRODUCTION

Spinach (*Spinacia oleracea L.*) is an annual edible flowering plant whose leaves have been used for nutrition since prehistoric times. Spinach is an annual herb that belongs to the Amaranthaceae family and originated in Persia. Spinach can be differentiated based on leaf structure, which includes curly leaves with a dark green colour, long smooth leaves, and semi-savoy leaves. Spinach grows vigorously in cool, moist locations with some shade. However, it can tolerate a lot of conditions, including direct sunlight. Spinach is rich in antioxidants because it has a high content of bioactive compounds, including Vitamin C (ascorbic acid), phenolic acid and other nutritional substances that are very low in carbohydrates and fats (Pérez-Marín, Torres, Entrenas, Vega, & Sánchez, 2019). Although spinach has high nutritional value, it has a short shelf life during preservation and storage, especially for fresh leaves.

Drying is the most common method to preserve food from the growth of microbes in order to extend its shelf life [1]. It can be done by eliminating the water inside the food and heating it up to a specific value [2]. However, this will not only prevent some biochemical reactions but also affect the physical and chemical quality of a food, such as texture, colour, bioactive compounds, and phenolic content [2]. Colour is the primary sensory signal essential to the consumer when it comes to setting people's standards about the expected taste and flavour of food and drink [3]. In the past decade, many new technologies have been invented to solve this problem by developing different approaches, such as microwave dehydration, ultrasonic dewatering, hot air dehydration, etc. In order to analyze the complexity of the drying mechanism, several mathematical and numerical modelling are used [4].

*Corresponding author: norawanis@unimap.edu.my

2. MATERIAL AND METHODS

2.1 Cultivation of Brazilian spinach plant

The production of fresh Brazilian spinach was developed at the Institute of Sustainable Agrotechnology (INSAT) located in Padang Besar, Perlis, Malaysia. The simple enclosed hydroponic system was designed to grow these plants, as shown in Figure 1. The fresh Brazilian spinach is commonly ready to be harvested at weeks 4-5 of cultivation. The harvested leaves were cleaned using tap water to remove any dirt attached to the leaves. Only the uniform size and exact color of the leaves were selected for further processing.

Figure 1: Cultivation of Brazilian spinach using an enclosed hydroponic system.

2.2 Drying of Brazilian spinach samples

About 10g of the fresh leaves were weighted and evenly distributed in a single layer on the sample tray, as shown in Figure 2. The experiments were conducted at four temperature levels of 30, 50, 70, and 90°C with 3 replications. A total of 12 experiment sets were performed. Throughout the experimentation, the sample weight was recorded at each drying time interval. The interval was set depending on the drying conditions. For instance, the samples were weighed every 30 minutes when dried under 30 and 50°C. Meanwhile, for the samples dried under 70 and 90°C, the weight was determined every 10 minutes until the weight of the samples was constant.

Figure 2: Drying of samples in a single layer using a hot air dryer.

2.3 Determination of Color Changes

An average of six readings was taken from individual samples of Brazilian spinach-dried herbal leaves using a colorimeter (Figure 3). The collected data were available in the form of L*, a* and b* color space (CIELAB). The total color difference (ΔE) was calculated by using the following equation:

$$\Delta E = \sqrt{[(L_* - L_0)^2 + (a_* - a_0)^2 + (b_* - b_0)^2]} \quad (1)$$

Where L0, a0 and b0 are the control values for the initial leaves' color before the drying process.

Figure 3: Colorimeter.

2.4 Determination of Textural Properties

The firmness of the fresh and dried leaves was determined using a texture analyzer. TA4/1000 probe was used in this experiment (Figure 4). Texture expert software was used to capture the force, time, and distance that gave a penetrating texture profile during the analysis process.

Figure 4: Textural properties analysis using TA4/1000 probe.

2.5 Mathematical Modelling of Drying Kinetics

The Statistical Package for the Social Sciences (SPSS) software was used to analyze the curve fitting of the hot air oven drying data. The experimental moisture ratio (MR) was compared with the predicted MR by 6 established thin-layer drying models (Table 1).

Table 1: Established thin layer drying models.

S.No.	Model Name	Model Equation
1	Page	$MR = e^{(-kt^n)}$
2	Henderson and pabis	$MR = ae^{(-kt)}$
3	Newton	$MR = e^{-(kt)}$
4	Modified page	$MR = e^{[-(kt)^n]}$
5	Two Term	$MR = ae^{(-k_0 t)} + be^{(-k_1 t)}$
6	Midilli	$MR = ae^{(-kt^n)} + bt$

The moisture ratio (MR) was calculated with the data of experimental moisture content using the equation below:

$$MR = \frac{M_i}{M_o} \quad (2)$$

where *Mi* = moisture content at different drying times and *Mo* = initial moisture content.

The coefficient of determination (R^2), root mean square error (RMSE) and Chi-Square (X^2) were used to evaluate the efficiency of the fits. The most excellent and reliable model used for the critical selection was based on the lowest value of RMSE & X^2 and the highest value of R^2. The equation of these parameters is presented as follows [6]:

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})}{N-Z} \quad (3)$$

$$RMSE = (\frac{1}{N}\sum_{i=1}^{N}(M_{pre,i} - MR_{exp,i})^2)^{\frac{1}{2}} \quad (4)$$

$$R^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{\sum_{i=1}^{N}(\overline{MR_{exp,i}} - MR_{exp,i})^2} \quad (5)$$

Where $MR_{pre,i}$ indicates estimated moisture content, $MR_{exp,i}$ represents experimental ratio, N indicates the number of observations during the drying process, and *n* represents the number of constants.

3. RESULTS AND DISCUSSION

3.1 Drying Characteristics of Brazilian spinach leaves

The drying curves of Brazilian spinach at different temperatures are presented in Figures 5 to 8. The moisture content of the Brazilian spinach reduced from 93.41 % to 9.21%, 8.51%, 9.26% and 9.30% at temperatures of drying 30, 50, 70 and 90°C. The moisture ratio at 50, 70, and 90°C, except 30°C, decreases drastically with the increasing drying time, as shown in Figures 3 to 6. This can be due to a rising in the energy of the water molecule because of an increasing temperature and also because of a greater difference in the partial vapor pressure in the drying air to the vapor pressure at higher temperatures of the moisture in the leaves, which results in faster evaporation of moisture from the Brazilian spinach. Only the 30°C showed a decrease in moisture ratio constantly when drying time increased, this was due to the low temperature. The energy of the water molecules was significantly low and caused the water content inside the leaves to require a long time to evaporate [5].

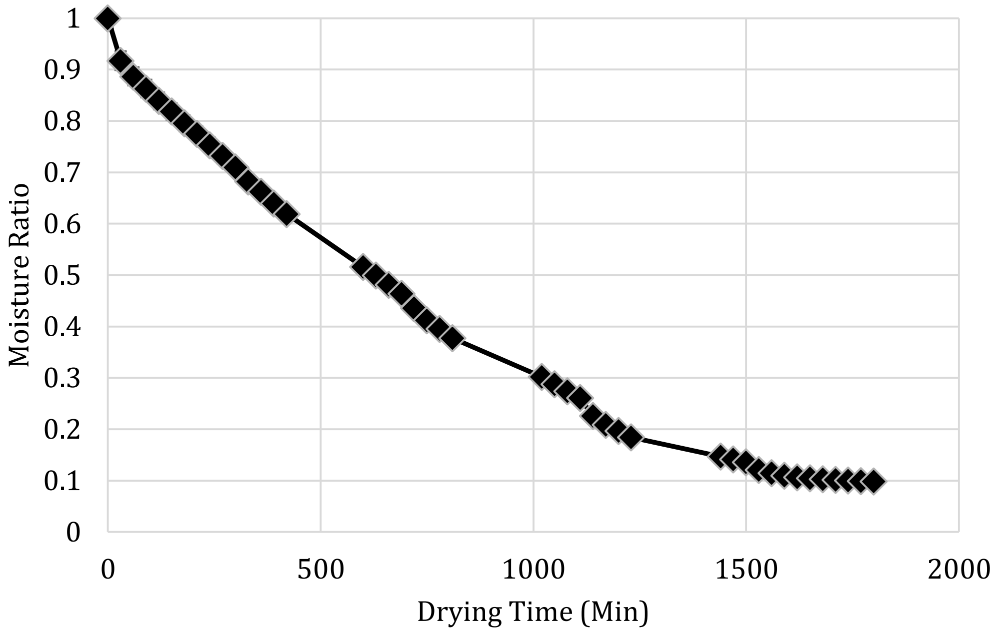

Figure 5: Hot air oven drying curves of Brazilian spinach leaves at 30°C.

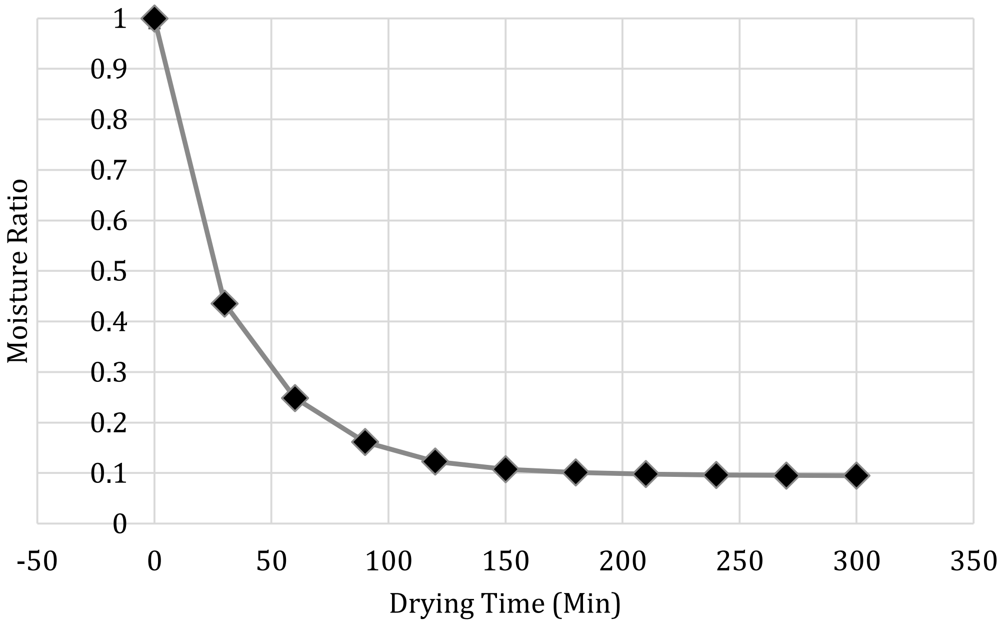

Figure 6: Hot air oven drying curves of Brazilian spinach leaves at 50°C.

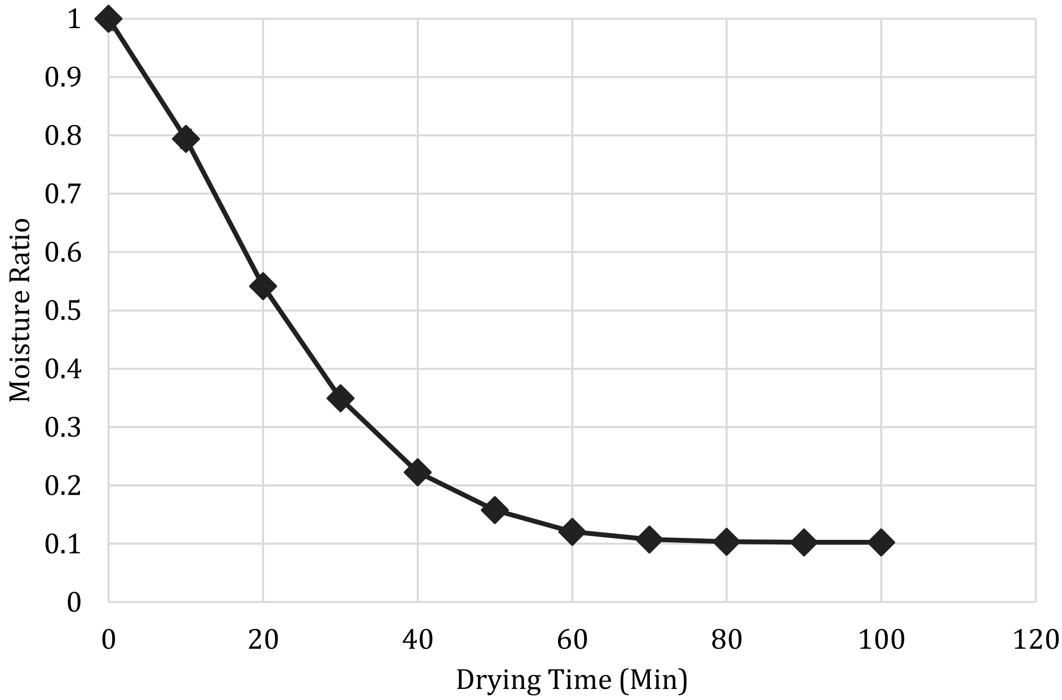

Figure 7: Hot air oven drying curves of Brazilian spinach leaves at 70°C.

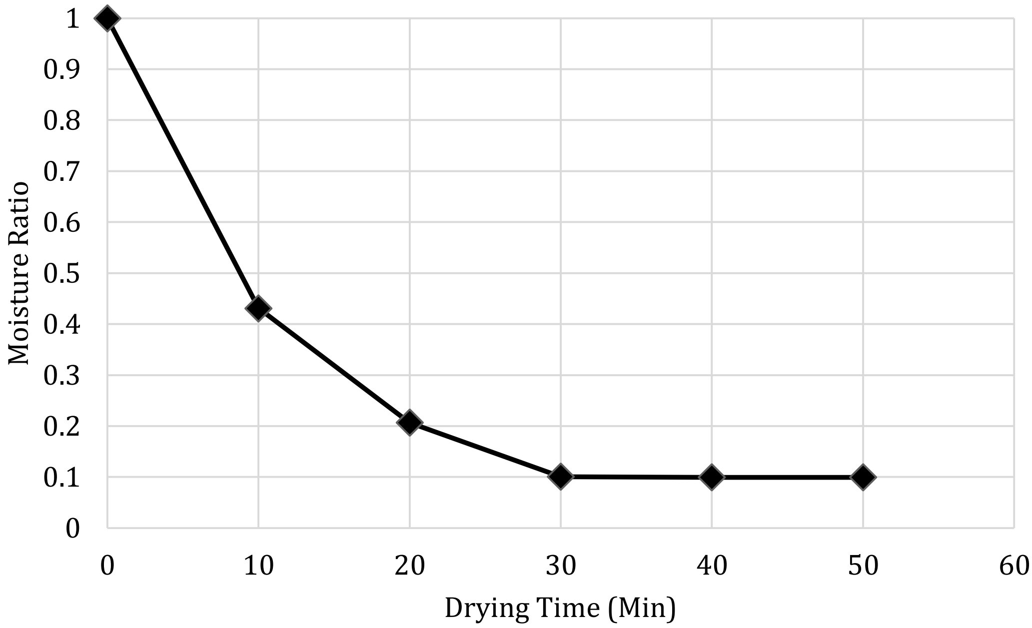

Figure 8: Hot air oven drying curves of Brazilian spinach leaves at 90°C.

Instead of moisture content curves, moisture ratio curves are more suited for revealing the drying characteristics of fruits and vegetables [6]. The time required to dry the Brazilian leaves until the constant weight gained was 1800, 300, 100 and 50 minutes at 30, 50, 70 and 90°C, respectively. The partial vapor pressure of Brazilian spinach leaves and hot air reached equilibrium when the weight gained was constant.

3.2 Mathematical Modelling

The models used in the current study to describe the drying characteristics of Brazilian spinach are presented in Table 2, including the Page, Henderson & Pabis, Newton, Modified page, Two-term and Midili. To evaluate the models, chi-square (X^2), root mean square error (RMSE) and coefficient of determination (R^2) were used. Table 2 summarizes the statistical analysis findings for the six mathematical models.

From all the mathematical models, the R^2 values collected from the statistical analysis were more than 0.95, which is in the acceptable range [2], and the value of R^2 in both two term and Midilli model was the highest (R^2 = 1.0000). Simultaneously, the values of RMSE and X^2 for the Midilli model also showed the lowest compared to other mathematical models. The values of X^2 and RMSE in the Midilli model were 4.5716×10^{-7} and 0.0005, respectively. In general, the lower values in RMSE and X^2 and higher value in R2 were desired to evaluate the mathematical model of drying Thus, as reported by results from Table 2, where the Midilli model showed greater prediction, this model was selected as the ideal acceptable descriptions of drying characteristics of Brazilian spinach leaves. This result is similar to the research done by [7]. Their research observed the drying characteristics of *Clinacanthus nutans* leaves using an infrared drying technique.

Table 2: Statistical analysis of six mathematical models.

Model	Temperature (C°)	Constants				R^2	X^2	RMSE
Page	30	k=0.001	n=1.064			0.9998	1.3435×10^{-3}	0.0358
	50	k=0.174	n=0.494			0.9997	1.7020×10^{-4}	0.0117
	70	k=0.027	n=1.056			0.9985	1.8850×10^{-3}	0.0388
	90	k=0.162	n=0.739			0.9998	1.4283×10^{-4}	0.0093
					Average	0.9995	8.8538×10^{-4}	0.0239
Henderson and pabis	30	k=0.676	a =1.000			0.9999	5.7994×10^{-4}	0.0235
	50	k=0.020	a =0.958			0.9581	0.0284	0.1507
	70	k=0.033	a =1.026			0.9994	7.6832×10^{-4}	0.0248
	90	k=0.425	a =1.000			0.9961	3.4138×10^{-3}	0.0453
					Average	0.9884	8.2905×10^{-3}	0.0611
Newton	30	k=0.001				0.9999	6.7681×10^{-4}	0.0257
	50	k=0.022				0.9602	0.0240	0.1470
	70	k=0.033				0.9990	1.1379×10^{-3}	0.032
	90	k=0.077				0.9968	2.1114×10^{-3}	0.0411
					Average	0.9890	6.9822×10^{-3}	0.0615
Modified	30	k=0.001	n=1.064			0.9998	1.3435×10^{-3}	0.0358
	50	k=0.029	n=0.494			0.9997	1.7020×10^{-4}	0.0117
	70	k=-0.009	n=0.127			0.9985	1.8850×10^{-3}	0.0388
	90	k=0.085	n=0.739			0.9998	1.4283×10^{-4}	0.0093
					Average	0.9995	8.8538×10^{-4}	0.0239
Two term	30	k_0=0.001	k_1=0.001	a =9.611	b=-8.645	1.0000	2.5641×10^{-8}	0.0001
	50	k_0=0.033	k_1=0.001	a =0.875	b=0.123	1.0000	0.0000	0.0000
	70	k_0=0.055	k_1=0.035	a =0.000	b=1.039	1.0000	4.5927×10^{-5}	0.0052
	90	k_0=0.087	k_1=-0.040	a =0.988	b=0.012	1.0000	4.0000×10^{-8}	0.0001
					Average	1.0000	1.1498×10^{-5}	0.0014
Midilli	30	k=0.001	n=1.110	a =0.950	b=-2.245E-5	1.0000	7.225×10^{-8}	0.0002
	50	k=0.067	n=0.753	a =1.000	b=0.000	1.0000	7.5570×10^{-7}	0.0007
	70	k=0.011	n=1.373	a =1.002	b=0.001	1.0000	7.5570×10^{-7}	0.0007
	90	k=0.077	n=1.057	a =1.000	b=0.002	1.0000	2.4500×10^{-7}	0.0003
					Average	1.0000	4.5716×10^{-7}	0.0005

3.3 Color Changes

Figure 9 shows the values of total color difference (ΔE) in the drying process. The highest total color difference was at 30°C with the value 31.9 ± 2.4. From a physical observation, the color of leaves for the samples dried at 30°C looks darker compared to the other samples, which dried at 50, 70 and 90°C (Figure 10). This finding contradicted the study by [8], who achieved the lowest value of ΔE when dried at the lowest drying temperature of 50°C of Moringa leaves. The study done by [9] also concluded that the hot air-dried peppermint leaves showed increases in total color difference ΔE when air-drying temperatures increased.

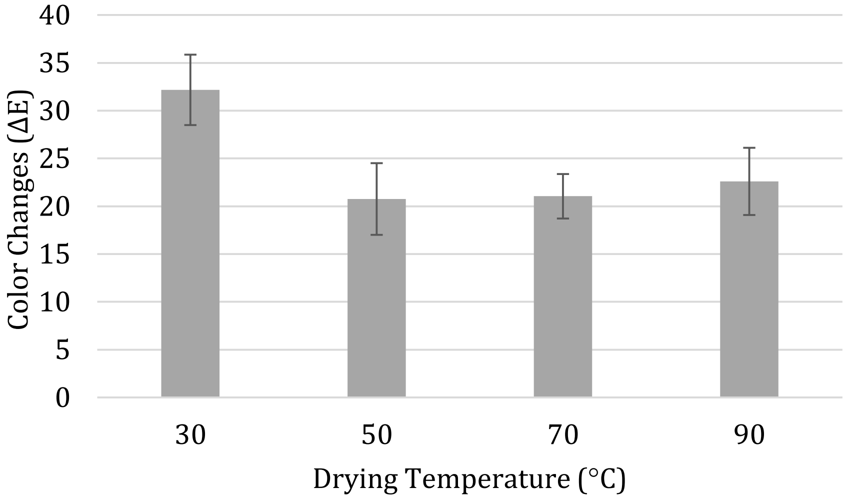

Figure 9: The value of ΔE at different temperatures.

Figure 10: The actual color of the samples after drying under (a) 30°C, (b) 50°C, (c) 70°C and (d) 90°C.

3.4 Texture Analysis

From the results obtained (Table 3), the drying process decreased the hardness of the Brazilian Spinach leaves at all drying temperatures (30, 50, 70 and 90°C). This may be because when the leaves undergo the drying process, the water inside the leaves is removed, which indicates that the leaves lose their turgidity and the structure of leaves break down, causing the hardness of Brazilian spinach leaves to decrease [9]. Springiness results show that dried Brazilian spinach leaves at low temperatures (30°C) recorded the highest elasticity. This finding indicates that the dried Brazilian spinach leaves had a higher capacity to restore their original state after deformation when the force applied was removed. A similar finding was obtained when the apples were dried under different temperatures [10]. The springiness value of the samples decreased when the drying temperature increased to 70 and 90°C. This observation might be due to the changes in structure in the cell membrane caused by the loss of moisture content of the Brazilian spinach drying process.

Table 3: Textural analytical of Brazilian spinach at different temperature.

Drying Temperature (°C)		30	50	70	90
Hardness (N)	Fresh Leaves	15.18 ± 1.51	19.03 ± 3.44	17.65 ± 3.10	17.76 ± 1.01
	Dried Leaves	8.65 ± 1.46	11.61 ± 3.23	11.28 ± 2.55	5.82 ± 0.26
Springiness(mm)	Fresh Leaves	13.57 ± 2.32	47.11 ± 17.70	7.86 ± 1.25	11.19 ± 1.71
	Dried Leaves	40.11 ± 16.19	29.06 ± 7.11	6.52 ± 2.96	12.61 ± 6.63

4. CONCLUSION

The drying characteristics of Brazilian spinach leaves under different temperatures were investigated. This study disclosed the important influences of drying temperature on moisture ratio, color changes, hardness and springiness on Brazilian spinach leaves. The drying temperature has affected the drying time required. When the temperature increased, the drying time reduced. This is due to the rising in the energy of the water molecule because of an increasing temperature and also because of a greater difference in the partial vapor pressure in the drying air to the vapor pressure at higher temperatures of the moisture in the drying air to the vapor pressure at higher temperatures of the moisture in the leaves, which results in faster evaporation of moisture from the Brazilian spinach. It was found that the Midilli model was the best mathematical model to evaluate the characteristics of drying in Brazilian spinach. As compared to the previous study, this model was suitable for predicting the moisture ratio of a product which is in a thin layer exactly compatible with Brazilian spinach leaves. Overall, the best drying temperature for preserving the color and texture of Brazilian spinach was 50°C.

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