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Curcuma longa L. Leaf: Kinetic Study Using Different Drying Methods

Monick Cristina Braga, Ellen Caroline Silverio Vieira*, Márcio Caliari, Tatianne Ferreira de Oliveira

School of Agronomy, Federal University of Goiás-UFG, Goiânia, Goiás, Brazil

***Corresponding author:** Ellen Caroline Silverio Vieira, School of Agronomy, Federal University of Goiás-UFG Goiânia, Goiás, Brazil. Tel: +18073553614; Email: ec.sv@hotmail.com

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Abstract

This work aimed the use of *Curcuma longa* L. leaves through the kinetic study of different drying methods and its influence on the content of phenolic compounds and color variation of the dried leaf. The leaves were dried by convective (60°C) and microwave drying (900W power). Mathematical modeling using various models was performed, as follows: Lewis, Page, Henderson and Pabis, Wang and Singh, and logarithmic models were used to adjust experimental kinetic data. The results showed that the drying time of microwave was 60 times lower than hot air drying. Page model was the best adjusted the drying kinetics data by both methods. The phenol content was higher in the dry leaf (370.86±0.65 mg Gallic Acid Equivalent (GAE). g_{sample}^{-1}) by microwave ($p < 0.05$) than in the hot air dried leaf (367.52±0.60 mg GAE.g_{sample}^{-1}), showing phenolic content greater than three times the fresh leaf (109.60±0.76 mg GAE.g_{sample}^{-1}). It was observed that the drying process does not influence the color variation of the dried leaf.

Keywords: Development of By-Products; Hot Air Drying; Microwave Drying; Sustainability

Introduction

Curcuma longa L. is a perennial plant that grows wild in tropical Asia and is widely cultivated in Brazil. Its rhizome is widely used as an important seasoning that adds yellow color and characteristic flavor to a large variety of Asian and Brazilian dishes, as well as processed food products, and has antioxidant, antitumor and anti-inflammatory activity [1]. During commercial cultivation of the rhizome the leaves of the plant are discarded, leading to the waste of great potential of natural antioxidants [2]. Drying is a conservation method that is based on reducing the water content of food, thus reducing the speed of chemical reactions and growth of microorganisms. Dry products have several advantages to wet products, such as reduced costs with storage and transportation. Convective drying is a very popular drying method because it has a low cost of implantation and easy operation. The main disadvantage of convective drying is its long process time, with low energy efficiency, especially in the period of decreasing drying rate. However, the use of this method may lead to a reduction in the quality of the food, whether due to changes in color, loss of nutrients or changes in texture [3].

Microwave drying can offer some advantages such as uniform power supply and high thermal conductivity inside the food, as well as high quality of the final product. This technique also reduces the drying time. The study of the kinetics of food drying during the microwave heat treatment has been a subject of interest in several works [3,4,5,6]. The objective of this study was to understand and optimize the *Curcuma longa* L. leaves, convective and microwave drying process, by performing kinetic study and mathematical modeling with empirical models.

Material and Methods

Sample Collection and Preparation

Turmeric leaves (*Curcuma longa* L.) were collected (February 2015) at the Mara Rosa - GO (14°00'10.9"S 49°07'11.8"W) Cooperative of Turmeric Producers (Cooperaçafrão). The leaves of plants of 15 months were harvested at dawn, stored in nylon bags and immediately transported to the Department of Food Engineering, at the School of Agronomy of the Federal University of Goiás, Goiânia-GO, under controlled temperature of 20°C. The period of harvesting of the turmeric leaf was determined in previous experiments comparing the phenolic content of the leaves of plants 60, 61, 62, 63, 64, 65, 66, 67, 68, 69 and 70 weeks old to obtain maximum content of phenolics.

The turmeric leaves were selected for visual appearance (typical green coloration and integrity), washed in running drinking water, sanitized in sodium hypochlorite solution 0.1 mL. L^{-1} for 15 min, centrifuged (CE410 Incalfer, São Paulo, Brazil) for the removal of excess surface moisture. The leaves had the stems removed and were cut manually into 2 cm squares for the drying process (Figure 1).

Figure 1: Leaf of *Curcuma longa* L. sanitized (a) and chopped (b).

Methods of Drying *Curcuma longa* L. Leaf

The turmeric leaves were submitted to convective drying in an air circulating oven of multiple perforated stainless steel trays (trays of 0.207 m^2, 290 holes per m^2, 1 cm in diameter) (Tecnal TE-394/3, Piracicaba-SP, Brazil). The operation occurred at 60°C, with an airflow of 0.83 m. s^{-1}.kg of $leaf^{-1}$ with 70% relative humidity (drying air). The drying air temperature was determined by a thermostat, and the speed and humidity through an anemometer (Icel Mark, model NA-3070). The chopped leaves were placed in the trays at an area density of 1 kg.m^{-2} and an initial mass of 207.0 +/- 0.03 g, with layer 1 cm high. Five trays were used simultaneously in each of the four replicates. The sanitized and dried trays had their mass determined in a semi analytical digital scale (BL3200H, Shimadzu, Kyoto, Japan) of 0.01 g precision before the placement of the leaves, at the time of the beginning of the drying, every 15 minutes in the first two hours, and every 30 minutes, after that period, until constant mass.

Microwave drying was performed in a microwave oven of 900 W of power, 23 L of capacity, 2.45 GHz of microwave frequency (MEF 33, Electrolux, Stockholm, Sweden). The operation occurred at 100% power, with an initial power density of 18 kW/kg of material. The chopped leaves were placed in unperforated glass trays at an area density of 1 kg.m^{-2} and an initial mass of 50.00 +/- 0.03 g in a layer 1 cm high. One tray was used in each of the 20 replicates. The dry and sanitized tray had its mass determined in a semi-analytical digital balance (BL3200H, Shimadzu, Kyoto, Japan) of 0.01 g precision before the placement of the leaves, at the time of the beginning of the drying, and every 15 seconds until constant mass. All weighing was performed in the minimum time needed to avoid temperature oscillation in turmeric leaves.

The initial moisture content of the turmeric leaves was determined, in triplicate, from a representative sample of the collection, by dehydration in oven (404/D, Nova Ética, São Paulo, Brazil) at 105°C until constant mass, as recommended by AOAC [7]. The moisture content along the drying stages was determined based on the reduction of the mass of water in relation to the dry mass present in each tray. The drying rate was defined as the variation of water content on a dry basis between two consecutive weighing in relation to the elapsed time interval [4].

Mathematical Modeling

Five mathematical models widely used in the literature for agricultural products drying experiments were studied: Lewis [8], Page [9], Henderson and Pabis [10], Wang and Singh [11] and Logarithmic. The mathematical models used in the drying kinetics of turmeric leaf are shown in Table 1, respectively. Statistical 10 software (StatSoft Inc., Tulsa, Oklahoma, USA) was used for non-linear regression of the data for curve modeling drying process. The criteria used for choosing the best adjustments was based on the determination of the regression coefficient (R^2) and the value of the Relative Mean Error (RME) described by Equation 1 [12]:

$$RME\ (\%) = 100\ \frac{\sum_{i=1}^{N} \frac{\left|x_{exp}^{i} - x_{calc}^{i}\right|}{x_{exp}^{i}}}{N} \qquad (1)$$

Na qual: RME = relative mean error; x_{exp}^{i} = experimental moisture; x_{calc}^{i} = calculated moisture; N = number of repetitions.

Referentially, to be considered a good fit, the model should achieve the highest and closest possible linear regression coefficient values (R^2) of the unit (1.0) and, concurrently, the lowest RME and values lower than 10% [12].

Model	Equation
Lewis	$\frac{x_t - x_e}{x_i - x_e} = e^{-kt}$ (2)
Page	$\frac{x_t - x_e}{x_i - x_e} = e^{-kt^a}$ (3)
Henderson &Pabis	$\frac{x_t - x_e}{x_i - x_e} = ae^{-kt}$ (4)
Wang & Singh	$\frac{x_t - x_e}{x_i - x_e} = 1 + ct + dt^2$ (5)
Logarithmic	$\frac{x_t - x_e}{x_i - x_e} = ae^{-kt} + b$ (6)
Where, a, b = dimensionless parameters of the models, c = linear time parameter (s^{-1}), d = square time parameter (s^{-2}), k = drying constant (s^{-1}), x_t = moisture content at a time t ($kg_{water}.kg_{dry\ sample}^{-1}$), x_e = moisture content at equilibrium ($kg_{water}.kg_{dry\ sample}^{-1}$), x_i = initial moisture content ($kg_{water}.kg_{dry\ sample}^{-1}$).	

Table 1: Mathematical models applied to *Curcuma longa* L. leaf drying curves

Phenolic Compounds Determination and Color Analysis

For the determination of phenolic content, four replicates of the extracts were made from representative samples of each treatment according to Chan et al. [13]. The extracts were prepared by homogenizing 1 g of sample with 50 ml of methanol for one hour on a magnetic stirrer (RH Basic 1, IKA, Staufen, Germany), filtering in filter paper and storing the extract in an amber bottle at -18°C until the time of analysis.

The total phenolic content (TFC) was quantified as described by Chan et al. [13] with modifications. 300 µl of turmeric leaf extract were mixed with 1.5 ml of the Folin-Ciocalteu reagent (10% v/v) and 1.2 ml of sodium bicarbonate solution (7.5% w/v) in then incubated in the dark at room temperature. After incubation for 30 min, the absorbance was recorded at 765 nm. A standard curve of gallic acid was constructed (y = 0.005x + 0.038, R^2 = 0.999) and the total phenol content was expressed as mg gallic acid equivalent (GAE) per gram of sample. The analysis was performed in triplicate.

The determinations of instrumental color parameters (L*, a* and b*) were performed in a colorimeter (Hunter-Lab, Reston, Virginia, USA) according to a method described by Paucar-Menacho et al. [14], using the Euclid equation to determine the color variation relative to the fresh leaf (Equation 7). Ninety repetitions of color analysis were performed per representative sample of each treatment.

$$\Delta E = \sqrt{\left(L_d^* - L_f^*\right)^2 + \left(a_d^* - a_f^*\right)^2 + \left(b_d^* - b_f^*\right)^2} \qquad (7)$$

Statistical analysis

The experimental data were statistically verified by ANOVA in a randomized block design using the Tukey test (p≤0.05). Calculations were performed using Statistica 10 (StatSoft Inc., Tulsa, Oklahoma, USA).

Results and Discussion

Kinetics of *Curcuma longa* L. Leaf Drying

Figures 2 and 3 show the average behavior of the drying rate during drying, by convection and microwave, and their kinetics.

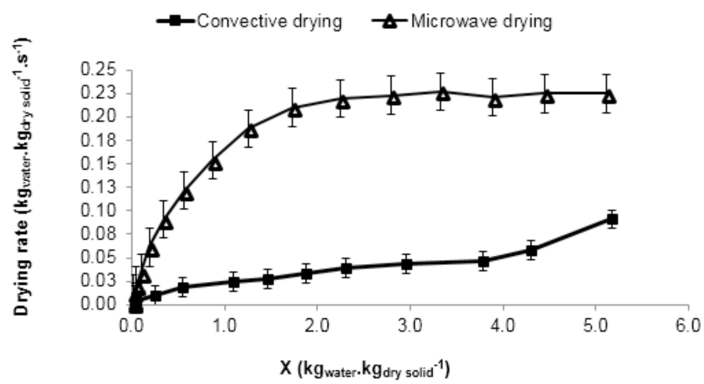

Figure 2: Drying rate (mean of repetitions) of *Curcuma longa* L. leaves during convective and microwave drying.

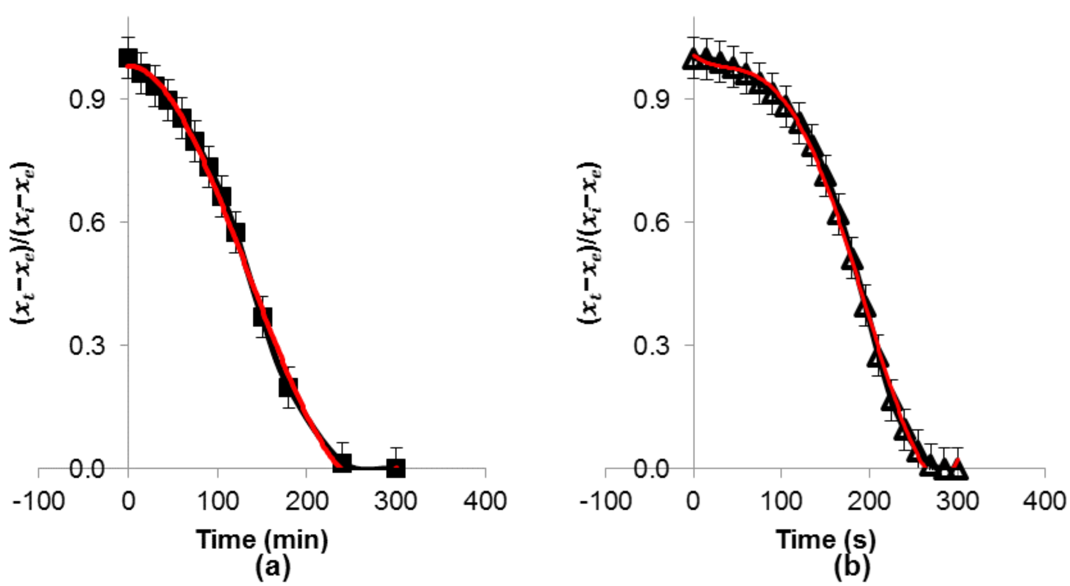

Figure 3: Moisture rate ($\frac{x_t - x_e}{x_i - x_e}$) kinetics (mean of repetitions) for convective **(a)** and microwave drying **(b)** of *Curcuma longa* L. leaves and adjustment of the Page model.

These results show that the microwaves drying presented drying rates higher than those presented by the convective drying ($p < 0.05$), which led to a drying time 60 times lower. The equilibrium humidity of the dried turmeric leaf by the two processes did not differ statistically ($p > 0.05$) and was 0.30 $kg_{water}.kg_{dry\ solid}^{-1}$, which means a reduction of 93% in moisture content of the fresh leaf. Despite the difference in velocities, the kinetics of drying of turmeric leaf by convection and microwave presented similar behavior.

During microwave drying it is possible to observe the existence of a period of constant drying rate. In this period drying is governed by the conditions of the surface of the food, little dependent on its nature, since its surface behaves like the surface of the water, and it extends for all the time in which the humidity of the interior of the same is able to replace the surface moisture withdrawn in the process. From the moment that the evaporation rate of the surface water is higher than the rate of replacement of moisture from the interior to the food surface, the drying rate decreases, characterizing the period of decreasing drying rate, which can be observed in both processes drying process.

The water transfer speed inside the turmeric leaf is dependent on several factors, the drying temperature being the factor that influences the most. From the interpretation of the drying rate curves it is possible to infer that the temperature during the microwave drying is superior to the convective drying, as well as the heat transfer rate. This can be explained by the fact that the heating of polar materials (in this case, mainly water) with the use of microwaves is faster and more uniform, since they directly absorb the energy of the equipment [15], while the convectively heated material has a slower temperature rise and the heat is not uniformly distributed by the slow transfer of heat from the medium to the product and from the exterior of the product into its interior [16]. These differences may justify the identification of a period of constant rate of drying only in microwave drying. In drying foods containing a large amount of bioactive compounds, softer temperatures are used to avoid thermal degradation of these compounds. This leaf-specific behavior of drying rates presents an acceleration region, where the mass transfer rate increases to the maximum speed, a region of constant speed, which occurs for almost half the drying period, and a deceleration region, where the drying rate decreases due to the decreasing drying rate period.

Mathematical Models

The parameters of the models with the corresponding coefficients of determination (R^2) and Relative Mean Error (RME) obtained for each drying method are shown in Table 2.

Model	Kinetic parameters	Convective drying	Microwave drying
Lewis	k	5.68E-03	0.27
	R^2	0.91	0.84
	RME (%)	20.25	32.32
Page	k (min^{-1})	1.10E-05	1.27E-04
	a	2.29	3.89
	R^2	0.98	0.99
	RME (%)	9.84	6.97
Henderson & Pabis	a	1.14	1.45
	k (min^{-1})	6.83E-03	0.35
	R^2	0.93	0.88
	RME (%)	27.03	30.45
Wang & Singh	c (min^{-1})	-3.67E-03	-0.31
	d (min^{-2})	0.00	-3.96E-02
	R^2	0.96	0.97
	RME (%)	16.36	13.35
Logarithmic	a	3.63	29.86
	k (min^{-1})	1.30E-03	6.00E-03
	b	-2.55	-28.67
	R^2	0.97	0.96
	RME (%)	13.80	15.63

Table 2: Identified models parameters, coefficient of determination (R^2) and Relative Mean Error (RME) for convective and microwave drying of *Curcuma longa* L. leaves

All models offered a reasonable fit to the data ($R^2 > 0.90$) except for the Lewis, and Henderson and Pabis models, which did not offer such a good fit to the microwave drying kinetics data (R^2 0.84 and 0.88, and RME 32.32 and 30.45%, respectively). For both drying stages, the Page model was the one that best adjusted the drying kinetics data, since it had the highest coefficient of determination ($R^2 \geq 0.98$) and low mean relative error (<10%), indicating that this model can be used successfully to predict the kinetic behavior of turmeric leaf drying by convective and microwave drying. The modular values of the parameters found for microwave kinetics are higher than those found for convective drying ($p<0.05$), indicating a higher drying rate in this process.

Naidu et al. [17] researching the drying of dill by convection with different air humidifies in association with radiofrequency and infrared also found the Page model as the best fit to the data, where the drying rate constant k for convective drying at 50°C was higher than this work (3.0E-03) and lower than that found by Tasirina et al. [18] for convective drying of kaffir lime leaves (> 0.0312) at the same temperature, where Page model was also the best fit. Borah, Hazarika, Khayer [19] found that the Page model was the most adequate to predict the behavior of the kinetic drying of whole and sliced turmeric rhizome (*Curcuma longa* L.), which shows that this is the most suitable model for predicting the drying kinetics of the plant of *Curcuma longa* L. as a whole, under the conditions studied.

Phenolic Compounds and Color

Important bioactive compounds found in turmeric leaf are phenolic compounds, known as the main class of natural antioxidants in plants [20]. Bhardwaj et al. [21] attributed to the secondary metabolites, such as tannins and flavonoids, the antioxidant and antimicrobial properties of the *Curcuma longa* L. leaf. The total phenolic content of the leaves of fresh and dried turmeric by convection and microwave, as well as the color variation suffered by the dried leaves, are given in Table 3.

Turmeric leaf	Total phenolic content *	ΔE
Fresh	109.60±0.76[a]	-
Convective dried	367.52±0.60[b]	14.44±0.07[a]
Microwave dried	370.86±0.65[c]	14.18±0.10[a]
Results are presented in mean ± SD. Different letters in the same column indicate significant difference ($p<0.05$). *Total phenolic content: mg gallic acid equivalent (GAE). g_{sample}^{-1}.		

Table 3: Total phenolic content and color variation of fresh and dried *Curcuma longa* L. leaves

The results evidenced that the content of phenolic compounds present in the fresh and dry leaves was significantly different ($p<0.05$). The dry leaves presented total phenolic content on a wet basis higher than that of the fresh leaf, resulting from the concentration of the compounds present in the leaf by the removal of water. The dry leaf by microwave presented the highest total phenolic content ($p<0.05$) indicating that there was degradation of phenolic compounds higher in the leaves submitted to convective drying. The microwave drying allowed a 238% increase in the phenolic content in wet basis, compared to the fresh leaf, while the convective drying allowed a 235% increase. This behavior can be attributed to the lower drying time obtained by the microwave method, despite the assumption that the leaves have reached higher temperatures during the drying stage. Chan et al. [13] also obtained higher degradation of the phenolic content in convective dried leaves of *Curcuma longa*. An alternative to avoid degradation of these compounds is the use of negative pressures (vacuum) during the drying step, so that it occurs in less time and/or temperature.

The total phenolic content found in this work is 27.5 times the content found by Chan et al. [13] for *Curcuma longa* L. leaves. This difference is probably due to soil, crop and climate differences between the state of Goiás (Brazil) and Selangor (Malaysia). Another important factor was the harvest of the leaves for this work during the period of maximum content of phenolics, while those of the work mentioned above were purchases in the trade without control of the harvest period. Dhaouadi et al. [22] found in commercial dried henna leaves a phenolic content lower than that found in this study (28.52 mg $GAE.g_{dried\ hena\ leaf}^{-1}$), indicating that the dried turmeric leaf may have antioxidant capacity superior to the work cited. Uribe et al. [23] studying peppermint vacuum-drying found a total phenolic content for the fresh leaf and dried under vacuum at various temperatures ranging from 11.56 to 27.12 mg $EAG.g_{dry\ matter}^{-1}$, inferior to the one found in this work, indicating the high phenolic content present in turmeric leaf when compared to other leaves of therapeutic use or as spice.

The color variation in vegetables during drying is due to the degradation of pigments and the formation of new colored compounds through non-enzymatic reactions, such as the Maillard reaction. In vegetables of predominant green coloring the variation of color during the drying is mainly due to the reduction of the intensity of the green coloration and reduction of the luminosity, making the products darker. The color variation of a vegetable during drying may indicate the degradation of nutrients such as carotenoids, flavonoids, phenolics, chlorophylls, among others. The color of the product can then be used as a process parameter for optimizing the drying step (time and/or temperature control), avoiding the degradation of important compounds [24].

The drying process did not influence the color variation of the turmeric leaves ($p>0.05$), indicating that the possible higher temperature used in the microwave drying caused a color change similar to the long period of exposure of the convective drying (Figure 4). The color variation in the leaves during drying may be associated with the degradation of chlorophyll and other compounds with antioxidant capacity, such as phenolics. The two drying methods presented identical moisture content and color variation ($p> 0.05$), indicating a possible relationship between these two parameters, since both are dependent on the time and temperature of the drying process (heat transfer). Changing the visual appearance may cause rejection of the product by the consumer when used as a spice.

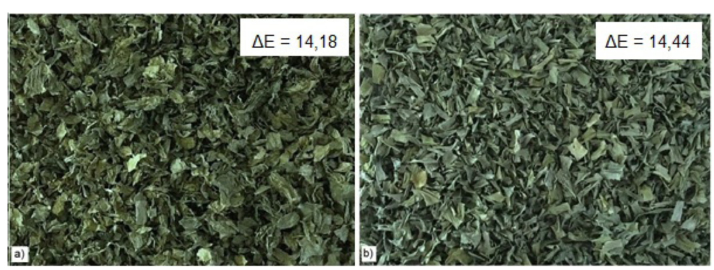

Figure 4: *Curcuma longa* L. leaves dried by microwave (a) and by convection (b)

Conclusion

According to the results obtained experimentally, drying of turmeric leaf by the microwave method was the best process, among those studied, to obtain a dried leaf, since it causes less degradation of the phenolic content and requires of less time to obtain dry leaf with the same color variation and moisture content as the product obtained by convective drying. It can be concluded that the utilization of the turmeric leaf may be an alternative for the use of this residue, which is discarded by the farmers, contributing to a better industrial sustainability.

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