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Physical and chemical characteristics and drying kinetics of turmeric (*Curcuma longa L.*)

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This study aimed to characterize the physical and chemical composition, antioxidant activity, essential oil yield, drying kinetics and fit to mathematical models, color parameters, particle size and scanning electron microscopy of fresh turmeric rhizomes (*Curcuma longa* L.). The physical and chemical composition of turmeric showed technological interest, with standards consistent with those reported in the literature. The essential oil has potential for further studies and applicability in food products, as well as use as preservative with antioxidant action. The Midilli model was the one that best fit the drying kinetics of turmeric. The results also allowed analyzing soluble, insoluble and total fibers and SEM, and it was found that there is perspective of using this raw material for the development of new products.

Key words: Turmeric, antioxidant activity, drying kinetics.

INTRODUCTION

The contribution of synthetic additives to the advancement of the sensory characteristics of foods and improvement of their life-of-shelf is unquestionable, which significantly contributes to the progress of food industries. However, global trends seek solutions to the partial or total substitution of synthetic by natural substances in order to

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improve the quality of foods (Filho et al., 2000).

Within a wide range of natural dyes, turmeric or saffron (*Curcuma longa* L.) is an orange-yellowish rhizome that provides the extract with its main pigment been curcumin. Turmeric has three structurally analogous curcuminoid dyes belonging to the class of diferuloylmethane ($C_{21}H_{20}O_6$) (Hamerski et al., 2013). Isolation and application of these compounds show properties that contribute to results that have proven that this pigment has therapeutic value, anti-inflammatory, anti-cancer, antibacterial and antifungal activity against foodborne pathogens and as preservative in food formulations (Naidu et al., 2009; Wang et al., 2009; Akran et al., 2010).

Currently, turmeric has increased participation in food products, mainly as dye in pasta, mustards, sauces (curry), cheeses, eggs and snacks like potato chips, and is also used in margarine and meat with antioxidant purposes (Volp et al., 2009).

Among various studies in literature related to the inherent properties of turmeric essential oils, the *in vitro* antimicrobial (Péret-Almeida et al., 2008) and antioxidant activities stand out (Jayaprakasha et al., 2006), which contribute to the interest in the development of new turmeric-based products.

In this context, due to the limited information concerning the preparation of turmeric-based products, this work aimed to evaluate rhizomes regarding physical characteristics and proximate composition, antioxidant activity, essential oil yield, drying kinetics and fit to mathematical models, color parameters, particle size and scanning electron microscopy.

MATERIALS AND METHODS

Fresh *C. longa* L. rhizomes collected in municipality of Rio Verde, GO, under geographical coordinates: 17°37'38, 26"S, and 50°45'18, 94"W, altitude 704 m above sea level, were used using hoe and manual pull-off into the ground at random. Rhizomes were then transported to the Laboratório de Frutas e Hortaliças, Instituto Federal Goiano – Campus Rio Verde, GO. Fresh rhizomes were selected, sorted cleaned, and stored at room temperature. Part of fresh rhizomes was packed in plastic bags, sealed and stored under refrigeration (4°C) until moment of specific analysis.

Methods

Sample preparation

For sample preparation, turmeric rhizomes underwent no pre-drying treatment. After cleaning with hypochlorite solution at 150 ppm for 15 min, the film involving rhizomes was removed using stainless knife. A fraction of fresh rhizomes was ground in a food processor to analyze the antioxidant activity and extraction of essential oils. The other fraction underwent manual slicing to obtain slices with 2.3 ± 0.1 mm in thickness, which were submitted to drying processes in an oven with forced air, with velocity for 5 m/s, circulation at temperature of 65°C to complete dryness to obtain the drying curve. After drying, the samples were ground, vacuum packed in bags and stored polyethylene temperature at 20° C until the time of subsequent analyzes.

Physical characterization of fresh turmeric rhizomes

The physical characterization of fresh rhizomes was performed as follows: fruit weight was determined by weighing in analytical scales with accuracy of three decimal places, and the results expressed in grams (g), length (mm) and equatorial diameter (mm) measured using digital calipers. The length/equatorial diameter ratio was determined by dividing the length by the diameter. Volume was determined by immersing the fruit in graduated polypropylene jar with distilled water, recording the volume (ml) of liquid displaced.

Proximate composition of turmeric flour

The physical and chemical composition of turmeric flour was determined as follows: moisture according to methodology No. 925.09 of AOAC (2000) up to constant weight; ether extract according to methodology No. 925.38 of AOAC (2000); crude protein content as the micro-Kjeldahl method No. 920.87 of AOAC (2000); ash, according to gravimetric method of AOAC (2000) No. 923.03, with calcination at 550°C and sample remaining in FORNITEC furnace model 1926, Brazil. Total, soluble and insoluble fiber were determined using the enzymatic-gravimetric method proposed by AOAC (2000), which consisted of screening the turmeric flour (50 mesh sieve - 0.297 mm) to submit to enzymatic digestion with amylase, protease and amyloglucosidase and subsequent to precipitation of soluble fiber in the presence of 78% ethanol. Analyses were performed in triplicate.

Quantitative analysis of the antioxidant activity

Assessment of the antioxidant activity of turmeric (ground fresh rhizome) was determined by the ability of scavenging the DPPH free radical, according to the methodology described by Pérez-Jiménez and Saura-Calixto (2006). The results were expressed as EC_{50} that relates to the reduction of 50% of the initial concentration of DPPH, this value was obtained by linear regression.

Extraction of essential oils and yield

For the extraction of turmeric essential oils by hydrodistillation, the Clevenger apparatus adapted to a round bottom flask was used. Fresh rhizomes were ground and weighed (300 g) and dissolved in 1000 ml of distilled water (AOAC, 2000). After extraction, the essential oil was stored under refrigeration in amber bottle. Essential oil yield was calculated based on the green and dry matter in moisture-free basis (MFB), using the formula proposed by Santos et al. (2004):

Equation 1: $\mathrm{To} = \frac{\mathrm{Vo}}{\mathrm{m} - \frac{\mathrm{mxU}}{100}}$

Where, To = essential oil yield (%); Vo = oil volume extracted (ml); m = sample weight (g); U = sample humidity (%).

Drying kinetics

For the drying kinetics, 1000 g of sliced sample with mean thickness of 2 mm were weighed and dried in oven with forced circulation in nylon screens trays, where the mass loss was monitored during the dehydration process until samples reached constant mass, with weighing performed at regular intervals of 20

Table 1. Mathematical models adjusted to the fresh turmeric drying kinetics.

Model designation	Equation
Lewis	RX=exp(-kt)
Page	RX=exp(-kt^b)
Henderson and Pabis	RX=a*exp(-kt)
Wang and Singh	RX=1+a*t+b*t^2
Logarithm	RX=a*exp(-k*t)+c
Midilli	RX=a*exp(-kt^b)+c*t
Diffusion Approach	RX=a*exp(-k*t)+(1-a)*exp(-k*b*t)

where: RX- water ratio (dimensionless); a, b, c, k, n- model constants; t- time (min).

min. Upon reaching the constant weight, the oven temperature was set to 105°C with the remaining samples for 24 h. After this period, the equilibrium water content was obtained.

From the weight loss data of samples during drying and the equilibrium water content, water ratios were calculated (Equation 1) and the water ratio curves as a function of the drying time were drawn. The temperature and the relative humidity of the environment outside the drying chamber were monitored by thermo hygrometer. The relative humidity inside the drying chamber was obtained through the basic principles of psychometrics, using the GRAPSI software.

Equation 2: $MR = \frac{U - U_e}{U_i - U_e}$

where: MR- moisture ratio, dimensionless; U- Water content in the product at time t, decimal dry basis (kg water kg^{-1} of dry matter); Ue- Equilibrium water content in the product, decimal dry basis (kg water kg^{-1} of dry matter); and Ui- Initial water content of the product, decimal dry basis (kg kg^{-1} of dry water).

The fresh turmeric experimental drying data were fit to mathematical models often used to represent the drying of agricultural products, as shown in Table 1, also using the statistical computer Statistics 2.0 software for adjustment of different mathematical models.

Color parameters

Instrumental color parameters (L*, a* and b*) of turmeric samples, fresh turmeric flour and compressed seasoning were analyzed by Hunter Lab Colorimeter, Model Color Quest II (Hunterlab, 1998).

Particle size

The particle size profile of turmeric flour was evaluated in vibrating equipment (Produtest) composed of six screens and background, with openings ranging from 1.41 to 0.053 mm (Dias and Leonel, 2006). To determine the uniformity index (UI), R% values obtained from coarse, medium and fine sieves were separately summed up and the result was expressed as percentage. Mean geometric diameter (MGD) was calculated with the equation of Handerson and Perry (1955), adapted to express the result in mm: MGD (mm) = 104.14 × 2^{MF}

Statistical analysis

Statistical analysis of data was performed using the ASSISTAT Software, through linear regression, variance statistical averages (Silva & Azevedo, 2009).

RESULTS

The physical characteristics of turmeric rhizomes are shown in Table 2. The mean weight, length, equatorial diameter, L/ED ratio and turmeric volume results were 16.41 g; 67.79 mm; 15.80 mm; 4.28 and 17.16 ml, respectively.

The average weight of turmeric rhizomes of this study were higher than those selected for planting reported by Chaves et al. (2011) using turmeric rhizomes with weights ranging from 5 to 15 g. According to diameter and length data (Table 2), variation coefficient values (VC%) were 0.13 and 0.27%, respectively, indicating homogeneity with low dispersion.

The geometrical characteristics of rhizomes showed the relationship of elongated length and diameter, indicating that the greater the L/ED ratio, the greater the length, where the variation coefficient value (VC%) of turmeric rhizomes was 0.23%, showing homogeneity with low dispersion. Ferreira et al. (2012) observed correlations between length and diameter, indicating the possible indirect selection of the amount of mass. The mean values and standard deviations of turmeric physicochemical parameters are shown in Table 3.

By studying turmeric according to culture and planting location, farming practices, fertilizer use and maturity of rhizomes, Krishnamurthy et al. (1975), Souza and Gloria (1998) and Cecilio Filho et al. (2000) analyzed samples collected from different regions of the state of Minas Gerais and showed the following proximate composition of turmeric rhizomes: protein from 7.01 to 8.51%; fiber from 5.50 to 7.22%, ash from 6.44 to 7.81% and starch from 35.30 to 39.9%, respectively.

Dried turmeric rhizomes showed average composition of 13.1% of water; 6.3% of proteins; 5.1% of fats; 69.4% of carbohydrates; 3.5% of ash and 2.6% of fibers. The content of turmeric curcuminoids may vary between 2 and 9%, depending on geographic conditions (Esatbeyoglu et al., 2012). In general, starch is the component present in greater proportion, as observed in this study by scanning electron microscopy.

The moisture content of turmeric flour in the present study was 7.83%, which was consistent with results found in the literature. The average value is within limits for vegetable flour established by legislation, which is 15% (ANVISA, 2005), ensuring product quality, since according to Barboza et al. (2006), low moisture content contributes to lower water activity, which is the amount of water available for microbial growth and most bacteria do not grow at water activities less than 0.91.

The antioxidant properties of *Cúrcuma longa* L. are of great interest in the food industry, in which curcumin is the major dye. This was already achieved in the dried samples. Value of CE_{50} = 338.9 g/L was determined by

Table 2. Descriptive results of turmeric weight, length, equatorial diameter, length/equatorial diameter (L/ED) and volume.

Variable (n=200)	Mean	SD	Minimum value	Maximum value	VC (%)
Weight (rhizome weight - g)	16.41	7.56	2.30	39.00	0.46
Length (rhizome - mm)	67.79	18.07	12.43	110.08	0.27
Equatorial diameter (rhizome - mm)	15.80	2.12	10.74	22.29	0.13
L / ED ratio	4.28	0.96	0.88	6.58	0.23
Volume (volume rhizome - mL)	17.16	7.97	5.00	40.00	0.46

n = Number of samples, SD = standard deviation VC = variation coefficient.

Table 3. Mean values and standard deviation of protein, ether extract, moisture, ash and fiber contents of turmeric flour (*Curcuma longa* L.).

Parameters	Mean and standard deviation
Protein (g/100 g weight edible protein)	8.28 ±0.46
Ether extract (g/100 g edible lipid weight)	4.07 ±0.24
Moisture (g/100 g weight of dry matter)	7.83 ±0.15
Ash (g/100 g weight of dry matter)	7.77 ±0.30
Soluble dietary fiber (g/100 g weight edible fibers)	1.01 ±0.50
Insoluble dietary fiber (g/100 g weight edible fibers)	8.66 ±0.58
Total dietary fiber (g/100 g weight edible fibers)	10.60 ±1.32

the percentage of DPPH scavenging for the antioxidant activity of the fruit.

Parize et al. (2006) reported in turmeric samples CE_{50} values of 242.1 and 501.4 µl/ ml, and turmeric pattern of almost 97% of curcumin showed CE_{50} value equal to 19.15 g/L, indicating that the higher the curcumin concentration, the lower the CE_{50} value and the higher the antioxidant activity.

Research methodologies for the study of curcuminoids have proven their oxidizing activity through the DPPH method with samples with concentration of up to 88, 80 and 68% and CE_{50} values of 56, 62 and 73 ppm, respectively (Naidu et al., 2009).

The average essential oil yield obtained in this study was 2.33%, with extract of light color, characteristic odor, giving the flavor of fresh rhizome. This yield was determined by the mass/mass ratio that showed value among those found in literature, but lower than 2.5 to 7.0% (Krishnamurthy et al., 1976; Viasan et al., 1989; Leung and Foster, 1996), 4.5 to 5.8% by Govindarajan (1980) and 4.4% reported by Péret-Almeida et al. (2008).

Table 5 shows the coefficients of the Midilli model adjusted for the drying of turmeric. The results of the particle size analysis are shown in Table 6, which shows the retention percentages of turmeric flour in sieves. Turmeric flour showed relative proportion among particles (UI) of 0.98% for coarse particles; 38.45% for medium particles and 60.57% for fine particles. The geometric mean diameter (GMD) was 0.046 mm.

The results on the calorimetry of sectioned rhizomes, turmeric flour and seasoning (*Curcuma longa L.*) are shown in Table 7.

DISCUSSION

No comparative data in relation to insoluble, soluble and total fiber content of turmeric were found in literature, but the study results showed satisfactory levels, indicating that turmeric is a source of dietary fiber.

According to Spiller (2001), dietary fiber plays an important role in reducing the risk of many diseases, especially the water soluble fraction, which has received much attention due to its various physiological functions.

The antioxidant properties were evaluated by various lipid peroxidation tests, as well as methods of DPPH radicals and chelating metals by Singh et al. (2010), which showed in their results that alpha-turmerone, an important component in fresh rhizome, is only smaller in dry rhizomes. In addition, the beta-turmerone content of dry rhizome is lower than the amount found in fresh rhizomes.

Among the methods used of the extraction of essential oils, extraction by hydro distillation was the method chosen for this work because the process uses water as a solvent, which is able to extract essential oils and not leaving toxic residues after extraction, even with the results by Naghetini (2006), who reported that extraction with non-polar solvent is simpler and faster and shows higher yield, 4.4 mL/100g, as compared to hydro

Table 4. Determination coefficient values (R^2), root of the mean square error (RMSE) and mean relative error (P) for mathematical models used in the drying process of turmeric (*Curcuma Longa* L.).

Model designation	65°C		
	R^2 (%)	RMSE	P (%)
Lewis	97.89	0.0817	0.0112
Page	99.93	0.1085	0.0149
Henderson and Pabis	98.36	0.2779	0.0382
Wang and Singh	99.32	1.4383	0.0182
Logarithm	98.84	8.55×10^{-11}	1.17×10^{-11}
Midilli	99.97	0.0016	0.0002
Diffusion Approach	97.90	0.0817	0.0112

Table 5. Coefficients of the Midilli model adjusted for the drying of turmeric.

Temperature (°C)	Midilli Model	R^2
65	$RX=1.004298*\exp(-0.978102*t^{1.671694})+0.005705*t$	99.97

Table 6. Particle size of turmeric flour (*Curcuma longa* L.).

Tyler	Holes (mm)	(PRi). g	(%R)	Ki	Ki ×%R
24	0.707	0.98	0.98	6	5.88
32	0.5	5.22	5.22	5	26.1
60	0.25	20.7	20.7	4	82.8
100	0.15	12.53	12.53	3	37.59
150	0.105	1.42	1.42	2	2.84
270	0.053	59.15	59.15	1	59.15
Bottom	0	0	0	0	0
TOTAL		**100**	**100**		**214.36**

Pri (g) = Weight retained in the sieve; % R = percentage retained on each sieve; Ki = conventional constant factors from 0 to 6 Ki x; R = total product obtained; Fineness Module (FM) = total product obtained x total product retained; UI = Uniformity index; mean geometric diameter (MGD) = 104.14 x 2 ^ FM = 0.046 mm.

distillation, whose yield was 2.8 ml/100 g.

According to Gounder and Lingamallu (2012), the higher essential oil yield was obtained from cured rhizome when compared with other rhizomes under study; however, 28 chemical compounds were identified in the oil from fresh rhizomes, some of which were not present in the oil from dried rhizomes due to losses during the processing steps (Cousins et al., 2007), demonstrating good alternatives to increase the antioxidant activity of foods during manufacturing.

Vilela and Artur (2008) conducted a survey of turmeric drying curves for different temperatures, wind speed and rhizome cuts and suggested that for faster drying and hence lower energy expenditure, the diameter of the material should be smaller. To be considered a good fit, the model must achieve linear regression coefficient values (R^2) higher and near as possible to the unity (1.0) and, concurrently, P (%) and RMSE values should be lower and near zero.

For the temperature used in drying turmeric, it was found that the models used satisfactorily fitted the experimental data, with Midilli model showing higher R^2 values (Table 4) and lower P (%) and RMSE values, adjusting better to the data observed, as compared to other adjustments.

The drying constant (k) for the Midilli model, which shows the effect of external drying conditions, was significant. Sousa et al. (2011) analyzed twelve models, and the Midilli model presented the best fit to describe the drying curves of turnip. According to Goneli et al. (2014), who evaluated the drying kinetics of black sage leaves and observed that several researchers working with other species of medicinal plants also concluded that the Midilli model was the best fit to experimental drying

Table 7. Mean values and standard deviation of the color parameters of sectioned rhizomes, turmeric flour and seasoning (*C. longa* L.).

Samples	Parameters		
	L*	a*	b*
1 (Rhizomes)	50.49 ±0.52[b]	25.57 ±2.38[a]	33.83 ±1.69[b]
2 (Flour)	65.11 ±0.17[a]	21.60 ±0.25[b]	40.40 ±1.00[a]

Different small letters in the column differ significantly at 1% probability.

data.

The analysis of color components L*, a* and b* in the samples demonstrated a significant variation in results, with L* ranging from 50.49 to 65.11.

For chromaticity coordinate a*, the color component ranges from (-60) green to (60) red. Turmeric samples showed values ranging from 21.60 to 25.57, which became more positive, indicating a tendency for red.

Chromaticity coordinate b* ranged from (-60) blue to (60) yellow, showing variation from 33.83 to 40.40 and a tendency to yellow on all samples. Turmeric flour was classified as orange-yellowish, with higher b* value, that is, high-intensity of yellow chroma, which is associated with the original color of turmeric. Tonnensen and Karlsen (1985) studied the effect of temperature on curcumin and found that is up to 100°C; there was no significant loss of curcumin, but at 125°C, there was degradation of 15.25% of pigment in relation to the initial content. Some researchers have demonstrated the physicochemical properties of yellow pigment obtained from turmeric in liquid and crystallized form maintained color at 80% for 6 months (Joshi et al., 2009).

Uniformity in particle size distribution is more important than particle size itself, because it facilitates good distribution of water in the mass. Thus, one should give preference to flour having particles of uniform size, especially those that pass through sieve number 30 (0.600 mm) and are retained in sieve number 60 (0.25 mm) (Guerreiro, 2006).

Regarding the raw material used in the food industry, particle size below 200 µis recommended to provide uniform color, and particle size equal to that of special wheat flour is desirable in the production of pasta, as this particle size presents no problems of rhizome particles to "stain" the mass during preparation (Marinozzi, 2002). Therefore, the turmeric flour under study showed greater amount retained in sieve 270 (0.053 mm), but it is within standards set by legislation (Brazil, 1996).

The oil is then held in vacuoles located in the cytoplasm. When these are disrupted by mechanical or physicochemical damage, oils retained is released, which for having a low boiling point, exhale a strong aroma (Hess, 1975).

Turmeric has not been used by the starch industry in Brazil because starch extraction is considered a secondary use, and rhizomes are only used to obtain dye and, in small proportions, for direct use in cooking (He et al., 1998). Given the number of research conducted on this topic, there is a great perspective of using residue from the extraction of essential oils and dyes as raw material for the production of starch.

Conclusion

With respect to turmeric characterization (*Curcuma longa* L.), it was possible to find specific properties, and the significant antioxidant activity confirms the potential use of the curcumin dye with preservative function in functional foods. It was found that the Midilli model presents the best fit to experimental drying data.

Insoluble, soluble and total dietary fiber showed satisfactory levels, indicating that turmeric as a source of dietary fiber should be studied in future studies, which should evaluate the profile of these compounds of great importance for the food industry.

Conflict of interests

The authors have not declared any conflict of interest.

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