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Effects of drying temperature on the bioactive and technological properties of turmeric (*Curcuma longa* L.) flour

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Abstract

The objective of this study was to evaluate the influence of drying treatment on the characteristics physical, chemical, technological properties and bioactive of turmeric flour. The flour was obtained from the drying of rhizomes in a forced air circulation oven at temperatures of 45, 55, 65 and 75 °C. The analyzes performed were: pH, instrumental color, microstructure, granulometry, water and oil absorption indices, water solubility indices, and antioxidant activity. The characteristics of the flours significantly affected were moisture, protein, lipid and ash contents. The antioxidant capacity with the DPPH radical, for flour at the drying temperature of 45 °C, presented the highest value 36.55 Mmol Trolox g^{-1}, and 7686.32 Mmol FeSO4 g^{-1} the FRAP radical at 65 °C.The phenolic content varied according to the solvent applied to obtain the extract, the mean values of total phenolic compounds for each temperature were: 0.419, 0.332, 0.316, 0.283 mg GAEa 100 $g^{-1}$for temperatures 45, 55, 65 and 75°C respectively. Water solubility index (WSI) and oil absorption index ranged from 12.45 g g^{-1} to 11.78 g g^{-1} and from 2.54 g g^{-1} to 2.49 g g^{-1}, respectively, for temperatures of 45 °C and 75 °C. The results of the present study indicated that temperature influences the physicochemical and technological properties of turmeric flour.

Keywords: antioxidants; solubility indices; infrared peaks.

Practical Application: The present work justifies the high demand of the turmeric rhizome (*Cúrcuma longa* L.) for the food, beverage, supplement and nutraceutical industry. The curcuminoids in the rhizome are variegated phenolic substances responsible for the yellow color and are recognized and used for medicines and medicines. The most common method used to dry turmeric or rhizome is sun drying. The long resolution process can be technological or curcuminoid content, biological and biological properties. Thus, it becomes important to research drying at various temperatures, characterizing physical, chemical and technological contents, establishing the best temperature for the stability of the bioactives inherent to the turmeric rhizome.

1 Introduction

Turmeric (*Curcuma longa* L.), also known as turmeric, golden ginger or turmeric from India, is a perennial plant originating in Southeast Asia, belonging to the Zingiberaceae family (Li et al., 2011). Iran is responsible for 92% of the world's saffron production, with a total of 336 tonnes year 2017, 75% of which are destined for export, according to recent data from the country's National Saffron Council (Villén, 2018).

Brazilian production is about 1% of the world's production and has the advantage of the season occurring in the Indian off-season, with the municipality of Mara Rosa – GO standing out. The annual production of the rhizome is about 5,000 tons in 250 hectares of planted area. According to the Cooperative of Turmeric Producers of Mara Rosa (Cooperaçafrão), the region accounts for about 90% of the production of Goiás, representing 26% of the national production (Serviço Nacional de Aprendizagem Rural, 2017). The turmeric plant produces bright yellow to orange rhizomes in the root system, which are a source of turmeric. One of the forms of turmeric marketing is powder, obtained after drying and grinding, which is used in cooking due to flavoring properties as seasoning (Damalas, 2011; Kakouri et al., 2017; Yewle et al., 2021).

In the food industry, it is used as a natural dye to replace synthetic dyes in products such as canned, chutneys, mustard, bread, yogurt, butter, cheese, among others, but the most important use is in curry preparation (Pereira & Stringheta, 1998; Osorio-Tobón et al., 2014; Borah et al., 2015). There are several studies related to turmeric rhizomes about the properties and uses, such as therapeutic, antimicrobial, antifungal, insecticide, anti-inflammatory and antioxidant properties (Singh, 2012; Khattak et al., 2005; Kita et al., 2016). Curcumin has anticancer, antiviral, antiarthritic, anti-amyloid and anti-atherosclerotic properties (Buduma et al., 2016), The rhizome is often used to treat gastric ulcers, parasitic infections, skin disorders, sprains, joint inflammation, and cold and flu symptoms (Harsha et al., 2016). Drying is a process widely used in food storage, which reduces the moisture content to significantly lower levels, making its availability unfeasible for the development of microorganisms, and minimizing the chances of physical, chemical and chemical

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damage and biochemical changes, thus increasing shelf life to considerable periods of time. Several turmeric drying studies have focused on physicochemical analysis, drying kinetics, and energy efficiency (Gan et al., 2017; Karthikeyan & Murugavelh, 2018; Lakshmi et al., 2019). However, some foods are extremely sensitive to the application of oxygen and heat, and uncontrolled drying process can cause food degradation (Haq et al., 2018; Azeez et al., 2019).

In this context, the objective of this study was to evaluate the influence of drying treatments (convective drying at 45, 55, 65 and 75 °C, in an oven) to evaluate the physicochemical, technological, structural and antioxidant activity characteristics of turmeric flours.

2 Material and methods

2.1 Obtaining turmeric flour

Turmeric (*Curcuma longa* L) flour was obtained from fresh rhizomes randomly collected with the aid of a hoe and by manual uprooting in the municipality of Rio Verde, GO, with geographical location of 17°37′38.26" S and 50°45′18.94" W, altitude of 704 m Flowchart Figure 1. The fresh rhizomes were selected, sanitized (100 ppm sodium hypochlorite solution for 10 minutes), peeled, evenly sliced with an average length of ±59.46 mm, width of 15.62 mm and thickness of 2.63 mm, and dried in a forced air circulation model (MAO35/2- Marconi) oven at temperatures of 45, 55, 65 and 75 °C until reaching constant mass. After the drying process, the rhizomes were crushed in a TECNAL® TE-651/2 cyclone mill with 18-mesh stainless steel sieve.

2.2 Physicochemical analyses turmeric flour

Moisture content was determined by the oven drying method (105 ± 1 °C) according to the AACC method (44-15 A). Crude protein analysis was performed by the Kjeldahl method, in which the total organic nitrogen content was evaluated according to the official method no. 960.52 of Association of Official Analytical Chemists (2019), with nitrogen conversion factor of 6.25. Ash content was determined according to AOAC method no. 923.03. (Association of Official Analytical Chemists, 2019). Lipids were determined according to AOAC method no. 920.39 (Association of Official Analytical Chemists, 2019).

The pH was determined according to AACC method no. 943.02 (American Association of Cereal Chemists, 2006). Instrumental color was measured at room temperature using the HunterLab Color Flex® EZ spectrophotometer. The results were expressed in color coordinates of CIELAB space (L* a* b*).

Mineral analysis was performed according to methodologies described by Pineli et al. (2015). First, 500 mg of flour was incinerated in a muffle furnace at 550°C for 4 hours, the ash was dissolved in 25 mL of 0.1 mol nitric acid solution. After filtration, calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), zinc (Zn) were determined by atomic emission spectrometry using an atomic absorption spectrometer (AAS-Vario 6, Analytik Jena). Phosphorus was determined by colorimetry, and potassium by flame photometer. Standard curves were expressed in mg/100 g of the corresponding minerals evaluated.

The values of minerals in mg L-1 in the sample were determined by Equation 1.

$$C=\frac{L.b.d}{v} \quad (1)$$

where: C = Concentration of the elements; L = sample reading, mg/L; b = volume of the flask which the ash of the sample went to the mL; d = sample dilution factor and v = sample volume, mL.

2.3 Technological functional analyses

The Water Absorption Index (WAI), Water Solubility Index (WSI), Oil Absorption Index (OAI) were determined according to methodologies described by Anderson et al. (1970). All analyses were carried out in triplicate.

2.4 Antioxidant activity assay with DPPH and FRAP

Antioxidant activity was determined by the DPPH method (1,1-diphenyl-2-picrylhydrazyl), according to Rufino et al. (2007) with absorbance reading at 517 nm in Nova 2000 UV

Figure 1. Production flowchart of turmeric flour (*Curcuma longa* L).

spectrophotometer Antioxidant activity was determined from a standard curve. Antioxidant activity was determined by the FRAP (Ferric Reducing Antioxidant Power) method, according to Rufino et al. (2006), results were expressed in μmol Trolox g^{-1}. Reading was performed (595 nm) 30 minutes after preparing the mixture. Total antioxidant activity was calculated using the equation of the line at absorbance equivalent to 1,000 μM of the ferrous sulfate standard, with analysis in triplicate.

2.5 Total phenolics in methanol, ethanol and water

Total phenolics content was determined by the Folin-Ciocalteu method (Agência Nacional Vigilância Sanitária, 2010; Rossi & Singleton, 1965). The extracts for the analysis were prepared with 100 mg of the sample in a vial in 10 mL of methanol:ethanol and/or water and stirred for one hour in the dark. Subsequently, a 0.1-mL aliquot of the filtrate obtained with addition of 7.9 mL of deionized water and 0.5 mL of Folin-Ciocalteu 2 N reagent (diluted 1:10) was filtered in filter paper. After 5 min in the dark, 1.5 mL of 20% sodium carbonate solution was added. After incubation at 25 °C for 2 h, the absorbance of the solution at 765 nm was measured using a Nova 2000 UV spectrophotometer. A standard curve was constructed using gallic acid at concentrations from 0 to 500 mg L^{-1}.

2.6 Total carotenoids

For the extraction of total carotenoids, the methodology recommended by Rodriguez-Amaya (1999) was used. 5.0 g of the samples were homogenized in mortars separately with 1.66 g of celite in 50 mL of cooled acetone. Each of the mixtures was filtered through filter paper and partitioned with 20 mL of petroleum ether in a separatory funnel. Subsequently, each of the extracts was washed with 300 ml of distilled water six times until the acetone was completely removed. The ether extracts were transferred to 50 mL volumetric flasks, attached to a funnel containing 5.0 g of anhydrous sodium sulfate under filter paper and the solutions were adjusted to volume with petroleum ether. The total carotenoid content was determined in a spectrophotometer at 450 nm. The result was expressed in ß-carotene equivalents ($\mu g g^{-1}$).

2.7 Scanning electron microscopy

The microstructural analysis of saffron flour was performed at the Multiuser Laboratory of High Resolution Microscopy of the Federal University of Goiás, using a scanning electron microscope (JSM-6610/Jeol®), equipped with EDS, ThermoScientific NSS SpectralImaging. The samples were previously degreased by Soxhlet extraction, method nº 1.122 (International Union of Pure and Applied Chemistry, 1979), placed in aluminum stubs with double-sided tape, bathed in an ultrathin film of gold (electrically conductive material), allowing the SEM to work in principle, by emission of electron beams with an accelerating voltage of 5 kV through a tungsten filament. Micrographs were performed at 400x magnification; 1500x and 3000x.

2.8 Infrared absorption spectrometry

The flours were characterized by Fourier-transform infrared absorption spectroscopy (FTIR), in Varian Excalibur 3100 FT-IR spectrometer in transmission mode. Each spectrum was collected from an average of 120 scans and resolution of 2 cm^{-1}, and the results were presented as mean values. Calibration was performed using KBr as blank, and the spectrum was recorded within the range from 500 to 4000 cm^{-1}.

2.9 Statistical analysis

The analyses were performed in triplicate, evaluated by analysis of variance (ANOVA), followed by Tukey test ($p < 0.05$) at 5% significance level, using Sisvar software version 5.6.

3 Results and discussion

3.1 Physicochemical analyses

The moisture contents (Table 1) of the turmeric (*Curcuma longa* L.) rhizome flours did not differ ($p>0.05$) between the drying temperatures, with an average of 7.28 g 100 g^{-1}, which is within the maximum recommended limit for flours of plant origin established by the legislation, which is 15% (Brasil, 2005), which guarantees the quality of the product, because the drier the product, the greater the microbiological stability.

The ash contents did not differ ($p>0,05$) between treatments with an average of 6.3 g 100 g^{-1}. This value was lower than the 7.33% reported by Chandel et al. (2011), but higher than that obtained by Braga et al. (2006), 1.5%. The lipid content was higher than that reported by Prasad et al. (2014), who found that turmeric has an average composition of 6.3% protein, 5.1% lipids, 3.5% minerals, 13.1% moisture and 69.4% carbohydrates.

Regarding protein contents, there was a difference ($p < 0.05$) between temperatures, and the flour dried at 45 °C had the

Table 1. Mean values and standard deviation of moisture, ash, ethereal extract (EE) and protein contents of turmeric (*Curcuma longa* L.) flour subjected to drying at temperatures of 45, 55, 65 and 75 °C.

Treatments	Moisture	Ashes	EE	Protein
	(g 100 g^{-1})	(g 100 g^{-1})	(g 100 g^{-1})	(g 100 g^{-1})
45 °C	7.51 ± 0.29[a]	6.23 ± 0.07[a]	7.45 ± 0.20[a]	11.13 ± 0.53[a]
55 °C	7.35 ± 0.09[a]	6.59 ± 0.08[a]	6.23 ± 0.56[a]	6.45 ± 0.22[b]
65 °C	7.19 ± 0.15[a]	6.04 ± 0.07[a]	6.15 ± 1.02[a]	6.07 ± 0.07[b]
75 °C	7.10 ± 0.14[a]	6.34 ± 0.05[a]	6.04 ± 0.16[a]	6.18 ± 0.20[b]
CV (%)	**2.92**	**1.11**	**9.2**	**4.11**

Means followed by the same letter in the column do not differ from each other by Tukey test, at 5% significance level. CV = Coefficient of variation.

highest protein content, with possible denaturation of proteins at higher temperatures.

3.2 Turmeric flour color

Color is one of the most important attributes in the quality of the final product as it can directly influence the acceptability by the consumer.

It can be verified (Table 2) that the L* values of turmeric flour ranged from 56.18 to 60.58, and the highest value was obtained at 45 °C. All treatments had b* values higher than a* values, which indicates that there is a predominance of yellow color in turmeric flours. Chromaticity (Chroma) represents the color saturation behavior in the sample, in which values close to 0 express more grayish colors, while values near 60 express more intense and vivid colors (Bem et al., 2012).

The highest h° value was observed in turmeric flour subjected to drying at 45 °C, average of 70.76, with predominance of intense yellow color. The hue angle (h°) ranges from 0° to 360° and indicates the color tone of the sample, with 0° or 360° indicating red tones, 90° indicating yellow tones, 180° indicating green tones and 270° indicating blue tones. All treatments led to values close to 90°, indicating the predominance of yellow color in the turmeric flours.

3.3 Minerals

In the mineral composition of turmeric flour (Table 3), the macromineral observed in largest quantity was nitrogen, with values of 14.70 g 100 g^{-1} and 42.95 g 100 g^{-1}, for temperatures of 45 °C and 75 °C, respectively, showing a slight increase with the increase in drying temperature. Thus, the nitrogen content is consistent with the protein content found in the present study.

The microminerals detected in greater quantity were 173.34 g 100 g^{-1} iron, the temperature of 55 °C, manganese 66.75 g 100 g^{-1}, ccopper 5.75 g 100 g^{-1}, zinc 30.75 g 100 g^{-1} in temperature de 45 °C. Arici et al. (2016), when researching the composition of taro (*Colocasia esculenta* L. Schott) flour, stated that the small differences in mineral profile between the flours dried at different temperatures may have resulted from their moisture contents, since minerals are heat-stable compounds.

According to the Food Composition Table (Universidade de São Paulo, 2013), the iron content naturally present in flours is 1.0 mg 100 g^{-1} and 0.9 mg 100 g^{-1} for wheat and corn flours, respectively. Therefore, it can observed that the iron contents found in turmeric flour (123.24 to 173.34 mg 100 g^{-1}) are above these values, which gives it properties for partial replacement in pasta processes, with consideration for the enrichment of flours with the possible decrease in the incidence of anemia, caused by iron deficiency. The highest zinc content was found at 45 °C (30.75 mg 100 g^{-1}). These values are higher than those presented in the same Food Composition Table (0.8 mg 100 g^{-1}). Boron content was 4.85 g 100 g^{-1} and 7.35 g 100 g^{-1}, for temperatures of 45 °C and 75 °C, respectively.

The chemical composition of turmeric rhizomes is influenced by several factors such as source plant, soil type,

Table 2. Mean values and standard deviation of color parameters L*, a*, b*, Chroma (C*) and hue angle (°h) of turmeric (*Curcuma longa* L.) flours obtained at different temperatures.

Treatments	Parameters				
	L*	a*	b*	C*	h°
45 °C	60.59 ± 0.24^{a}	26.90 ± 0.18^{b}	77.10 ± 0.52^{a}	81.66 ± 0.55^{a}	70.76 ± 0.06^{a}
55 °C	56.55 ± 0.04^{c}	26.55 ± 0.07^{c}	69.99 ± 0.32^{d}	74.86 ± 0.33^{d}	69.22 ± 0.04^{d}
65 °C	58.19 ± 0.07^{b}	27.56 ± 0.02^{a}	74.33 ± 0.20^{b}	79.28 ± 0.18^{b}	69.65 ± 0.05^{b}
75 °C	56.27 ± 0.28^{d}	26.68 ± 0.15^{c}	71.37 ± 1.01^{c}	76.19 ± 0.99^{c}	69.49 ± 0.18^{c}

Means followed by the same letter in the column do not differ from each other by Tukey test at 5% significance level. CV = Coefficient of variation.

Table 3. Descriptive values of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and boron (B) of turmeric flours subjected to drying at temperatures of 45, 55, 65 and 75 °C.

Macrominerals (g 100 g^{-1})	Temperature (°C)				Unit
	45	55	65	75	
N	41.04	41.99	42.11	42.95	g kg^{-1}
P	3.50	2.92	3.01	2.98	
K	18.50	20.05	20.00	21.00	
Ca	1.46	1.40	1.71	1.41	
Mg	2.75	1.99	2.18	2.10	
S	1.38	1.12	0.97	1.13	
Microminerals	**45**	**55**	**65**	**75**	
Fe	138.11	173.34	123.24	165.34	mg 100 g^{-1}
Mn	66.75	1.25	3.10	1.40	
Cu	5.75	4.65	4.30	4.25	
Zn	30.75	7.15	7.70	7.90	
B	4.85	5.60	5.10	7.35	

climate, fertilization, water availability, harvest time (first or second cycle) and storage time (Oliveira et al., 1992; Scartezzini & Speroni, 2000).

3.4 Hydrogen potential (pH), water absorption index, water solubility index and oil absorption index

The pH values (Table 4) of the turmeric (*Curcuma longa* L.) rhizome flours did not differ ($p > 0.05$) between drying temperatures. It can be observed that the water absorption index (WAI) was significantly affected by the increase in drying temperature. WAI expresses the amount of water absorbed by the starch and can be used as the gelatinization index, with the increase in temperature, freeing the hydrophilic active sites for binding with water, causing swelling of granules and increase in water absorption (Anderson et al., 1970; Gonzáles et al., 2009).

Spinello et al. (2014) evaluated turmeric flour and cassava flour, and observed that the former had higher values of water absorption indices and water solubility indices (7.69 $g.g^{-1}$ WAI and 21.42% WSI) than the latter (6.31 $g.g^{-1}$ WAI and 4.48% WSI). The solubility index of turmeric flours in this study significantly reduced with the increase in temperature (Table 2).

Kuttigounder et al. (2011) obtained higher water absorption values of 3.62 and 4.78 g g^{-1} for dry and cooked rhizome samples, respectively, compared to the isolated starch (1.07 g g^{-1}) at 30 °C. According to the authors, the thermal process, as well as the grating and drying process possibly changed the structure of the starch. In addition, they analyzed the amylose content for turmeric starch and found value of 48.4%, higher than that of potato starch, stating that the high amylose content is beneficial for the manufacture of extruded and fried snacks, particularly when low expansion, crispness and reduced fat absorption after frying are desired. Confirming these technological properties, the oil absorption index showed no significant difference as observed for the WAI.

3.5 Antioxidant capacity, carotenoids and total phenolic compounds

The study of the antioxidant properties of *Curcuma longa* L. is of great interest for the food industry, and curcumin is the main dye. Curcumin is the major component of *C. longa* rhizomes, accounting for about 2% of their dry weight. In addition to curcumin, there are more than 300 different components, including phenolics and terpenoids (Li et al., 2011; Gupta et al., 2013). The antioxidant activity by the DPPH method (Table 5) for turmeric flour obtained at drying temperature of 45 °C differed from the values of flours obtained at the other drying temperatures. Prathapan et al. (2009) reported that activity of polyphenoloxidase was decreased during heat treatment of turmeric rhizomes and it was almost completely inactivated when heated at 80 °C for 30 min. Regarding the reduction power of Fe^{+3} (FRAP), there were differences between treatments. According to Embuscado (2015), FRAP measures energy reduction, but cannot detect compounds that act by radical quenching (H transfer), particularly thiols and proteins; consequently, FRAP values have a weak relationship with other antioxidant measures.

Maniglia et al. (2015) obtained significant values of 74.4 µg g^{-1} and 66.6 µg $g^{-1}$for DPPH in turmeric residue and flour, respectively, which were dried at 35 °C for 24 h, proving the influence and loss of curcuminoids during drying.

Table 4. Mean values and standard deviation of pH, water absorption index (WAI), water solubility index (WSI) and oil absorption index (OAI) of turmeric (*Curcuma longa* L.) flours dried at temperatures of 45, 55, 65 and 75 °C.

Treatments	pH	WAI	WSI	OAI
		(g g^{-1})	(g g^{-1})	(g g^{-1})
45 °C	6.47 ± 0.39[a]	4.32 ± 0.07[b]	12.45 ± 1.08[a]	2.54 ± 0.04[a]
55 °C	6.58 ± 0.04[a]	4.88 ± 0.07[a]	10.05 ± 1.25[a]	2.34 ± 0.02[a]
65 °C	6.63 ± 0.04[a]	4.47 ± 0.01[ab]	10.91 ± 0.89[a]	2.43 ± 0.22[a]
75 °C	6.54 ± 0.05[a]	4.47 ± 0.27[b]	11.78 ± 0.51[a]	2.49 ± 0.63[a]
CV (%)	**4.69**	**3.48**	**8.61**	**13.75**

Means followed by the same letter in the column do not differ from each other by Tukey test at 5% significance level. CV = Coefficient of variation.

Table 5. Mean values of antioxidant capacity, using DPPH and FRAP radicals, and total phenolic compounds of the extracts (methanol, ethanol and water) of turmeric (*Curcuma longa* L.) flours dried at temperatures of 45, 55, 65 and 75 °C.

		Treatments			
		45 °C	55 °C	65 °C	75 °C
Antioxidant capacity	**DPPH (µmol Trolox g^{-1})**	36.55[a]	10.11[b]	9.94[b]	8.64[b]
	FRAP (Mmol) FeSO4 g^{-1})	5092.98[b]	1331.32[d]	7686.32[a]	4231.32[c]
Total phenolic compounds	**Phenols (methanol) (mg GAEa 100 g^{-1})**	0.600 ± 0.10[a]	0.517 ± 0.11[ab]	0.386 ± 0.03[b]	0.420 ± 0.01[ab]
	Phenols (ethanol) (mg GAEa 100 g^{-1})	0.607 ± 0.01[a]	0.450 ± 0.01[bc]	0.502 ± 0.05[b]	0.400 ± 0.01[c]
	Phenols (water) (mg GAEa 100 g^{-1})	0.05 ± 0.02[a]	0.03 ± 0.01[a]	0.06 ± 0.04[a]	0.03 ± 0.02[a]
	The average values total phenolic compounds (mg GAEa 100 g^{-1})	0.419	0.332	0,316	0.283
Carotenoids (µg g^{-1})		14.88[a]	10,15[b]	6,39[c]	5,90[c]

Means followed by the same letter in the column do not differ from each other by Tukey test at 5% significance level. CV = Coefficient of variation.

Queiroz Cancian et al. (2018) obtained values for DPPH and FRAP in turmeric extracts obtained from several solvents with different polarities, with values of 10.48% and 2.68%, respectively, in methanol.

Carotenoid contents were significant at temperatures of 45 °C and 55 °C, with wide variation, ranging from 5.9 μg g^{-1} to 14.88 μg g^{-1}. Singh (2012) observed for mature rhizomes and immature rhizomes of *C. longa* values of 0.47 μg g^{-1} and 0.66 μg g^{-1} in ethanol extract, lower than the values found in this study in petroleum ether extract. This may be related to the fact that carotenoids are a class of natural liposoluble compounds, with potential antioxidant properties in plants due to their chemical structure, and are also part of the antioxidant defense system in the human body. The alteration or loss of carotenoids during food processing and storage occurs through physical removal (e.g., peeling), geometric isomerization, and enzymatic or non-enzymatic oxidation (Müller et al., 2011).

Alvis et al. (2012) conducted a study with hydroalcoholic extracts of *C. longa* rhizomes and found no difference in phenol content using 75% and 95% ethanol (around 1800 mg GAE/L). For the ethanol extract of rhizomes, Salama et al. (2013) determined total phenolic content of 517.54 ± 0.049 mg GAE/mg extract and Himesh et al. (2011) reported a value of 11.24 mg GAE/g.

Total phenol content corresponding to 198.7 μg GAE/mg of dry extract was obtained for turmeric methanol extract (Batubara et al., 2012). According to Chanda & Baravalia (2010), phenolic contents of 32.88 mg g^{-1} and 41.73 mg g^{-1} were observed for methanol extracts of rhizomes and peel, respectively. Chen et al. (2008) found 21.4 mg g^{-1} of total phenols in methanol extract.

3.6 Fourier-Transform Infrared Spectra (FTIR)

By analyzing the FTIR spectra of the flours obtained at different temperatures in Figure 2, it can be noticed that all the flours showed the eight bands highlighted. The intense band at 1000 is typical of carbohydrates and is related to C-OH and CH_2 deformations. The band around 1000 may also be associated with the presence of curcuminoids, due to the stretching of the C-O-C bond found in curcumin and demethoxycurcumin (Mohan et al., 2012).

The acute peaks at 1436 cm^{-1} are typical of aromatic compounds with C=C group of the benzene ring and vibrations of the C-H group of curcumin, pigment present in turmeric flour (Govindaraj et al., 2014).

Band at 1511 cm^{-1} had high intensity for the sample dried at 65 °C. This band may also be associated with the vibrations of the lignin aromatic ring (Bilba & Ouensanga, 1996) and the bending of the C=O bond found in curcuminoids (Mohan et al., 2012). The band at 1627 cm^{-1} can also be associated with the mixture of stretching of the C=C and C=O bonds found in curcuminoids (Kolev et al., 2005; Mohan et al., 2012). The intensity of the band around 2,925.24 cm^{-1} may also be related to variations in the amount of amylose and amylopectin present in starches, because a lower amylose content results in a higher intensity of these bands (Kizil et al., 2002). The band close to ~3276.77cm^{-1} corresponds to the stretch of the O-H group present in the water molecule (Pereira et al., 2015).

3.7 Scanning electron microscopy (SEM)

Figure 3 shows the scanning electron microscopy of turmeric flour obtained from drying at temperatures of 45, 55, 65 and 75 °C (1, 2, 3 and 4), with A, B and C indicating magnification of 400x, 1500x and 3000x, respectively. It was possible to clearly verify the presence of loose starch granules and agglomerates (Maniglia et al., 2015). In images 2A, 2B and 2C it was possible to observe starch granules involved with proteins and fibers, indicative of the strong interactions between starch and the protein matrix reported by Queiroz Cancian et al. (2018) in observations in turmeric flour.

The observed starch granules of turmeric show two structures: triangular and ellipsoid oval (3A; 3B), but are predominantly characterized as ellipsoid oval, as already shown by Braga et al. (2006), and Leonel (2007), with sizes ranging from 10 to 35 μm.

In images with magnification of 1500x and 3000x, the structures seem to be irregularly shaped. Kuttigounder et al. (2011) stated that they consist mainly of starch, while other components such as protein, crude fiber and fat were also visible, but difficult to identify.

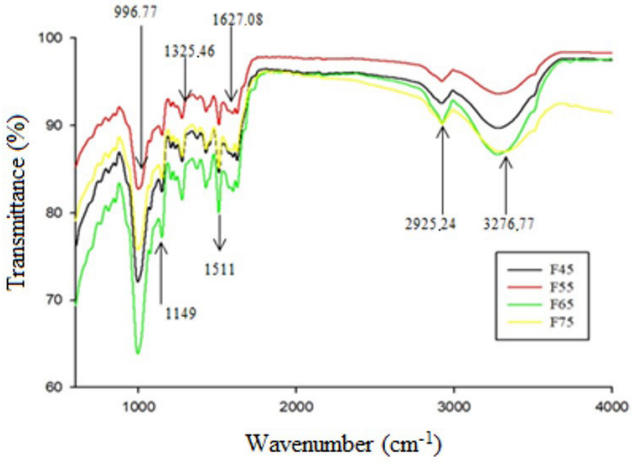

Figure 2. Fourier-transform infrared absorption spectra (FTIR) of flours produced from turmeric (*Curcuma longa* L.) rhizomes.

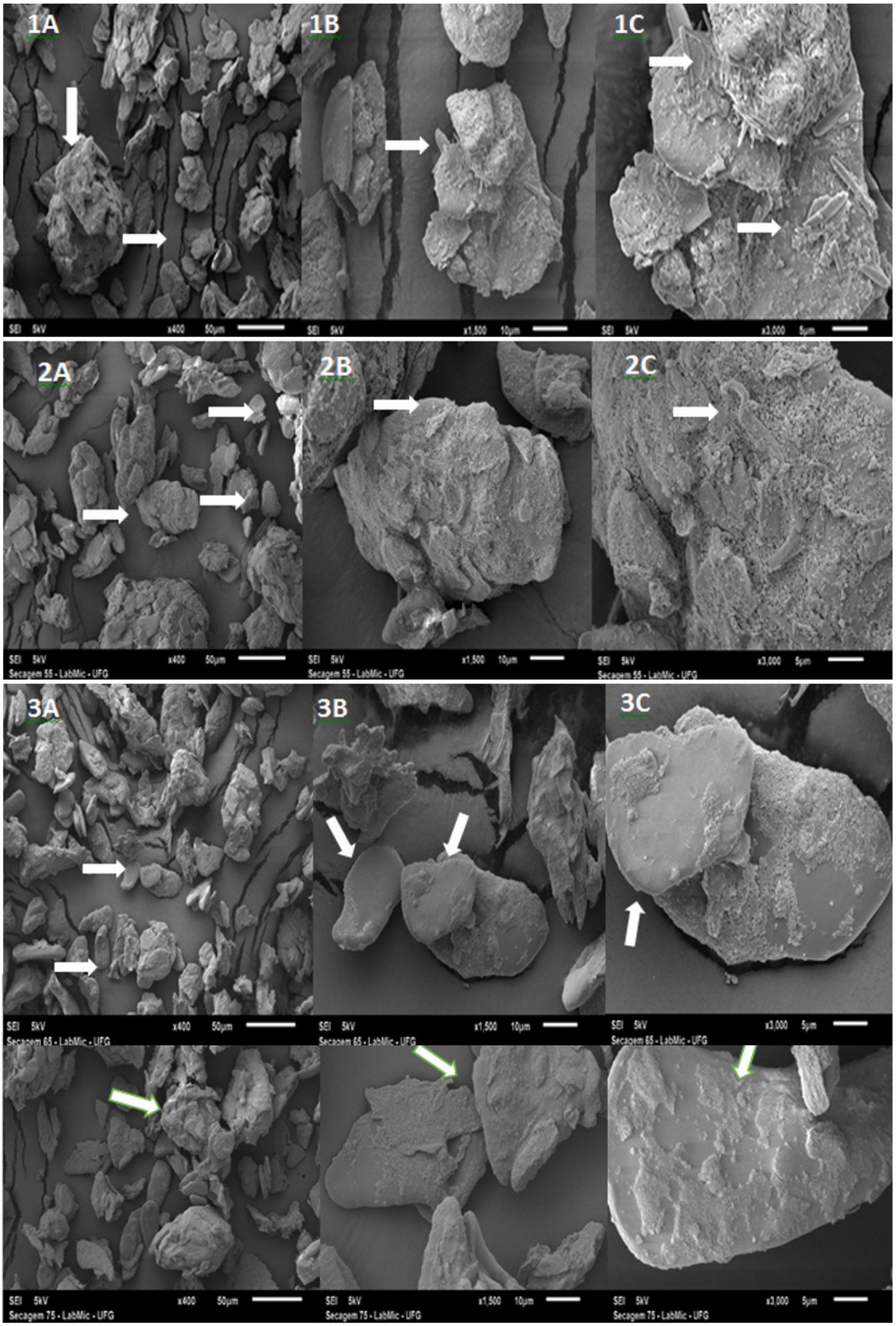

Figure 3. Scanning electron microscopy of turmeric flour obtained from drying at temperatures of 45, 55, 65 and 75 °C (1, 2, 3 and 4), with A, B and C indicating magnification of 400x, 1500x and 3000x, respectively.

4 Conclusions

Drying at temperatures of 45, 55, 65 and 75 °C played an important role in the physicochemical and technological properties of turmeric flour. Phenolic compounds are observed to be major contributors to antioxidant activity and drying temperatures have been shown to exert variable effects on individual phenolic compounds.

At 45 °C, the chemical composition of turmeric flour showed better parameters and higher antioxidant activity by the DPPH and FRAP methods. Among the technological properties, the water absorption index was significantly affected by the increase in temperature.

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