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Comparative analysis of the bioactive compounds of fresh saffron rhizome (*Curcuma longa* L.) and its commercial version as a powdered condiment

Análise comparativa dos compostos bioativos do rizoma de açafrão *in natura* (*Curcuma longa* L.) e seu condimento comercial em pó

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Saffron is a rhizome usually ingested in the form of powdered seasoning. However, the steps for its industrial processing can lead to losses of its bioactive compounds. In this context, the main objective of this research was to compare the content of bioactive compounds of fresh and dried saffron (commercial powder condiment) *Curcuma Longa* L. The methodology was based on the Analytical Norms of the Instituto Adolfo Lutz and references in the area of food science and technology. The results showed that fresh saffron suffers considerable losses during industrial processing for its conversion into commercial powder form. The losses of 20% in the amount of phenolic compounds in the commercial powder (from 485.34 ± 43.08 GAE g^{-1} in the fresh saffron to an average of 375.72 ± 25.77 GAE g^{-1} in the commercial powder), following similar behavior in carotenoid contents (average of 574.41 ± 42.81 g^{-1} for α-Carotene fresh saffron and average of 557.27 ± 41.34 g^{-1} for powder). Differing in bioactive values for flavonoids contents with higher contents for the commercial powder (average of 179.33 and 165. 56), higher in anthocyanins 165.56 ± 0.82 and 130.31±0.13 g CE 100 g^{-1}. Infrared measurements showed that industrial processing does not alter the most thermoresistant chemical compounds, inversely to the bioactive ones. The morphological analysis registered the presence of amyloplasts and fibrous bundles with attached starch granules. These data show the effect of processing this rhizome and the potential of saffron as an auxiliary to human health.
Keywords: saffron, condiments, bioactive compounds.

O açafrão é um rizoma de alto consumo na forma de condimento em pó. No entanto, suas etapas de processamento podem levar a perdas de compostos bioativos. Nesse contexto, o objetivo principal desta pesquisa foi comparar o teor de compostos bioativos do açafrão *in natura* e seco (condimento em pó comercial) *Curcuma Longa* L. A metodologia foi baseada nas Normas Analíticas do Instituto Adolfo Lutz e em referências analíticas publicadas internacionalmente na área de ciência e tecnologia de alimentos. Os resultados mostraram que o açafrão *in natura* sofre perdas consideráveis durante o processamento para sua conversão em pó comercial. As perdas de 20% na quantidade de compostos fenólicos no pó comercial (de 485,34 ± 43,08 GAE g^{-1} no açafrão *in natura* para uma média de 375,72 ± 25,77 GAE g^{-1} no pó comercial), seguindo comportamento semelhante nos teores de carotenoides (média de 574,41 ± 42,81 g^{-1} para o açafrão *in natura* e média de 557 0,27 ± 41,34 g^{-1} para pó). Diferindo nos valores bioativos para teores de flavonoides com teores maiores para o pó comercial (média de 179,33 e 165,56), maiores em antocianinas 165,56 ± 0,82 e 130,31±0,13 g CE 100 g^{-1}. Medidas de infravermelho mostraram que o processamento não altera os compostos químicos mais termorresistentes, ao contrário dos bioativos. Na análise morfológica, observa-se a presença de amiloplastos e feixes fibrosos, com grânulos de amido aderidos. Esses dados mostram o efeito do processamento desse rizoma e o potencial do açafrão como coadjuvante à saúde humana.
Palavras-chave: açafrão, condimentos, compostos bioativos.

1. INTRODUCTION

Saffron (*Curcuma longa* L.) is a plant native to Southeast Asia that belongs to the Zingiberaceae family. Its pear-shaped, often short and branched rhizomes, have a spicy flavor and an intense color ranging from yellow to orange. It is known in popular medicine to produce home remedies, in addition to being widely used in the form of a dry powder as a culinary seasoning in the preparation of various foods all over the globe and can also be sold in the form of fresh rhizomes and used as raw material for products other than cooking. This rhizome contains a multitude of benefits to human health, helping to combat cardiovascular disease, cancer, and oxidative stress [1-3].

This rhizome is rich in phenolic compounds, with a higher proportion of curcuminoids (70-75%), which are closely associated with high functionality related to antioxidant and anti-inflammatory activity, which are important in the prevention and treatment of various diseases. ranging from cancer to autoimmune, neurological, cardiovascular, and diabetic diseases [4-6].

However, the regular bioactive compounds to be found in this rhizome can possibly be altered during the process of obtaining and cultivating the rhizome until it arrives to be sold in supermarkets and other places, due to the loss of its compounds in the process of preparation, transport, and storage, as well as the temperature changes and the time it takes to reach the final consumer [7, 8].

In addition, current research shows that saffron has significant amounts of bioactive compounds, both in its commercialized powder form and in its fresh form, in addition to other forms of consumption from which we can obtain the physiological use of these compounds. [7-9]. However, there are few studies that make a comparative analysis of the possible losses imposed by the industrial processing that the rhizome undergoes to yield its powdered condiment.

Given what has been said, the objective of this work was to compare the content of bioactive compounds found in the fresh saffron turmeric rhizome and in the condiment powder sold in bulk in order to identify losses of bioactive compounds, chemical groups, and morphological changes.

2. MATERIAL AND METHODS

2.1 Sample collection

Fresh saffron (*Curcuma Longa* L.) samples were obtained from a tea and spice store located in the Metropolitan Region of the Municipality of Belém, State of Pará, Brazil (Latitude: 01º 27’ 21” S and longitude: 48º 30’ 16” W). The samples were transported in low-density polyethylene (LDPE) plastic bags to the Food Science Laboratory, located at the Faculty of Nutrition at the Federal University of Pará (UFPA).

Saffron samples sold in the form of powdered condiment were obtained from a supermarket located in the Metropolitan Region of the Municipality of Belém, State of Pará, Brazil (Latitude: 01º 27’ 08” S and longitude: 48º 30’ 13” W). The samples were transported in plastic pouches and sent to the Food Science Laboratory, located at the Faculty of Nutrition at the Federal University of Pará (UFPA).

2.2 Biometric characterization of fresh saffron

For the physical analysis, a sample of 8 fresh saffron rhizomes was selected and individually weighed in a semi-analytical scale (Bel brand, model L303i, Brazil). The biometric parameters were defined with the aid of a digital micrometer (150 mm 6”) manufactured by MEASURING; longitudinal and transversal measurements were assessed 3 times and registered in centimeters.

2.3 Preparation of fresh saffron sample for condiment powder

Washing and sanitization actions were carried out by immersion, using a 200-ppm sodium hypochlorite solution (part per million) for fifteen minutes. Afterwards, the rhizomes were washed in running water for one minute and dried with a paper towel at room temperature.

The leaves and bark contained in the rhizome were removed. After that, to obtain the powdered condiment, the rhizomes were crushed on a grater and dried in a greenhouse for 48 hours at 50 ºC, finally, ground in a willey knife mill (Willye, STAR FT 50, Brazil).

2.4 Physical-chemical analysis

To analyze water activity, commercialized saffron (CS) as a powdered spice and fresh saffron (FS) were placed in the direct measurement equipment using the Labmaster instrument (Novasina, Aw Neo Series 3TE, Suiça). The results were registered in triplicate.

To determine the moisture content, we used the methodology of Instituto Adolfo Lutz (2008) [10]. The total titratable acidity was verified according to the norms expressed by the Instituto Adolf Lutz (2008) [10] with results described in percentage (%) of citric acid.

The pH determination was accomplished using a pH meter (Nova Orgânica, model PA200, Brazil) according to the method nº 981.12 of the Association of Official Analytical Chemists (AOAC, 1997) [11] and using aqueous extracts of powdered saffron and fresh saffron. Both samples were diluted as follows, 1 gram of the sample for 100ml of distilled water, and performed in triplicate.

The analysis of Total Soluble Solids (TSS) was performed according to the analytical norms of the Instituto Adolfo Lutz (IAL, 2008) [10], NaOH (Sodium Hydroxide) was used at 0.01 N with a correction factor of 0.9986 for titration. Three dilutions of the samples were made in the proportion of 1g to 100ml of distilled water. This process was performed in triplicate and the results were expressed as percentage (%) of citric acid (100 g^{-1}).

The analysis of the pigments was carried out according to the methodology of Nagata and Yamashita (1992) [12]; with adaptations the reading took place in the UV-Vis spectrophotometer (KASUAKI, model IL-592, Brazil) at the wavelength of 663, 645, 505, 453 nm.

2.5 Analysis of bioactive compounds

2.5.1 Carotenoids

The determination of carotenoid content was performed according to the methodologies described by Rodriguez-Amaya (2001) [13] with adaptations, using a UV-Vis spectrophotometer (KASUAKI, model IL-592, Brazil). The absorbance reading took place at a wavelength of 450 nm for beta-carotene and 449 nm for zeaxanthin.

2.5.2 Total phenolic compounds

The total polyphenol content was analyzed using the Folin Ciocalteu test, as described by Ali Akbarian et al (2011) [14], with adaptations. The absorbance was determined using a UV-Vis spectrophotometer (KASUAKI, model IL-592, Brazil) at 760 nm of wavelength. A standard curve of gallic acid, made at a concentration of 100 to 500 mg/mL in Gallic Acid Equivalents (GAE), was used.

2.5.3 Flavonoid analysis

The flavonoid content was determined according to the methodology described by Lees and Francis (1972) [15]. The absorbance of the extracts was analyzed using a UV-Vis spectrophotometer (KASUAKI, model IL-592, Brazil) at a wavelength of 374 nm.

2.5.4 Vitamin C analysis

For this analysis, 0.01% 2,6-Diclorofenol Indofenol DCFI was prepared, 10 ml of the sample extract plus 50 ml of oxalic acid were placed in the Erlenmeyer flask, and the titration was subsequently performed until reaching a light pink color. The result was obtained in triplicate and expressed in mg $100g^{-1}$ [16]

2.6 Infrared spectroscopy

Fourier Transform Infrared Spectroscopy (FTIR) analyses of the samples were carried out in a Perkin Elmer spectrometer, Frontier model 98737 (Waltham, MA, USA) at 25 °C in the wavenumber range 4000-400 cm^{-1}. The sample spectrums were recorded by averaging 20 scans with 4 cm^{-1} resolution in transmission mode. The images were printed out from a plotter machine using Origin 8.0 software.

2.7 Scanning Electron Microscopy

The morphological analyzes of the powder samples were used to observe the granules structure in Scanning Electron Microscopy (SEM) (Tescan, model Vega3, Czech Republic), coupled with an X-ray energy spectrum dispersion system. With samples coupled to supports and metalized with Au/Pd (gold/palladium) to allow necessary electrical conductivity in the image formation process, at an Electron Beam Current of 85-90 μA.

3. RESULTS AND DISCUSSION

3.1 Biometric Results

In Table 1 we find the biometric parameters of the rhizomes with their respective weights and their transverse and longitudinal lengths.

Table 1: Biometric values of fresh saffron.

Parâmeters	Maximum	Minimum	Average and standard deviation
Transverse (cm)	145.52	40.82	101.52±38.35
Longitudinal (cm)	49.77	21.49	39.64±11.92
Weight (g)	73.97	10.02	37.53±22.50

*Data represent mean ± standard deviation of triplicates.

It is possible to observe a significant dispersion between the averages of all parameters, which evidences great variety of weights and lengths in the rhizomes that were analyzed. In the saffron biometric surveys carried out by Silvio et al. (2020) [17], a transverse average of 49.95 ± 12.53 cm, a longitudinal average of 15.38 ± 2.01 cm and average weight 8.11 ± 3.6 cm were found. The measurements found by the authors, compared with the values found for the saffron samples in this work are lower; this may occur due to the period of saffron harvesting [18].

Furthermore, in comparison with other rhizomes of the same saffron family (Zingiberaceae), the study by Basavaraj and Jayan (2020) [19] analyzed the ginger rhizome (Zingiber officinale Roscoe) after harvest and found the average transversal of 16.52 ± 3.71 cm and the longitudinal average of 9.75 ± 1.76 cm. It is posssible to find that, in comparison to ginger, saffron has larger dimensions, but with much higher standard deviations, showing a high size discrepancy between the analyzed raw material. Regarding weight, in the studies by Basavaraj and Jayan (2020) [19], the weight of the rhizome was also analyzed, and it ranged from 0.35 to 1.13 kg, with mean values of 0.764 kg. In light of this, the weight of saffron is also greater than that of ginger.

3.2 Physicochemical analysis

Physicochemical analyses are presented in Table 2.

Regarding water activity (a_w), it was observed that the highest value obtained from this analysis is found in the turmeric marketed with 0.65 at 24.9 °C while its fresh equivalent presented 0.44 at 25 °C. The absolute value of a_W indicates the safety of the amount of free water within the food, this being the only way that water is used by microorganisms. The possibility of microbial change in food becomes practically null in foods that have a_W values below 0.60 – as was found in the fresh value – although this does not mean these microorganisms and their actions are absent it indicates an excellent margin of food safety [20].

Tabela 2: Physicochemical analyzes.

Analyses	**commercialized saffron CS**	**Fresh Saffron (FS)**
Water activity (A_w)	0.65 ±0.00	0.44 ±0.00
Moisture (%)	5.68 ± 0.58	4.97 ± 0.48
pH	6.35 ±0.07	5.17 ±0.09
Total title acidity (%)	0.47 ± 0.153	0.27 ± 0.058
Total soluble solids (ºBrix)	0.25 ±0.00	1.00 ±0.00

*Data represent mean ± standard deviation of triplicates.

The moisture value in foods sold in dry forms, such as many food supplements, powdered formulas, and food condiments, should be as low as possible, according to the product's manufacturing process. In some cases, it may be necessary to select ingredient lots with less moisture content, or even consider the additional drying of the ingredient, so as not to change extrinsic factors which would generate unwanted product modifications and microbial growth [21].

In the samples of CS and FS, it is possible to observe that the former had the highest percentage compared to the latter. It is worth noting that the humidity of all components is below the maximum allowed (13%) [22], these differences in the results may be related to the drying method accomplished in the laboratory, which may have been more efficient than the industrial processing of CS. This is consistent with the studies of Silvio et al. (2020) [17], which relate different types of drying of a saffron variety, which showed that greenhouse drying was really more efficient, bringing a lower percentage of samples drying by the sun and by microwave.

In addition, the drying period of the product is also a key factor, given that the shorter the drying time of this product, the higher the moisture percentage in the saffron [23, 24]. This process may be also related to the amount of time it takes for the product to arrive at the supermarket and, consequently, at the consumers' homes, considering that a place of transport and storage that is not so efficient as to prevent this increase in moisture from occurring, can cause the change in texture coloring, flavor, nutritional value, and food quality [24].

Regarding the pH of the samples, it was possible to observe a superior result in the CS than in FS. This observation can be attributed to the alkaline nature of the turmeric itself. Regarding the CS, a higher value of pH could be associated with microbial contamination, which may have occurred during the production process [25]. The result is compared to the data of Osorio et al. (2020) [26] which compared saffron samples from conventional soils in different locations of

Colombia, it was also possible to find averages of 5.79 ± 0.01 to 6.74 ± 0.01 in conventional soils and 5.53 ± 0.01 to 5.79 ± 0.01 in agroecological soils.

Compared to the studies of Ajayi and Bankole (2020) [27] – which analyzed saffron in different post-harvest periods – after the harvest (0 days) values of 5.9-6.1 were found, after 15 days the pH values ranged around 5.2-6.8, and after 30 days the values were ranging around 4.8-6.5. Since the two samples CS and INS presented pH values around 5-6, it is possible to infer that the values match those found by Ajayi and Bankole (2020) [27].

Solid solubles include important compounds that are responsible for adding flavor and consequently received by consumers; the most important ones are sugars and organic acids. In studies by Silva et al. (2020) [28] on the ginger rhizome (*Zingiber officinale* roscoe) presented values of soluble solids of 6.0° Brix ± 0.48 (dry sample) higher than the values found in the saffron sample used in our research, a fact that can be explained by the difference in sugar concentration. The total titrable acidity determines the amount of organic acids (citrus, malic tooth others) in vegetable organs; when compared to the taro flour it was possible to observe an average acidity of 0.37 the tuber has similar values to those of the powder condiment derived from the saffron rhizome [29].

Plant organs tend to reduce the solidable total solid content (SSC) and total title acidity (TTA) during storage because they are consumed in plant respiration. Thus, turmeric saffron may have presented these SSC and TTA values due to its respiratory rate increasing during the time the product was kept in storage. In this sense, we conclude that the values of TTA and SSC were different from those found in the literature. Due to the timing of harvesting as well as of industry storage and spice trading, it is possible that whole rhizomes can also have their values modified [29].

3.3 Bioactive compounds

Bioactive compounds can be found in different foods, food products, and herbal samples. [30]. Its antioxidant action combats free radicals naturally produced through oxidation which, characteristically, reacts with DNA, RNA, proteins, and other substances possessing oxidative power, causing health damage, and contributing to aging and predisposition to degenerative diseases, such as cancer, atherosclerosis, rheumatic arthritis, besides preventing cardiovascular disease, type 2 diabetes [31, 32]. Given its vast capability for disease prevention, the comparative contents of the bioactive compounds in the FS and CF are shown in Table 3 to assess its possible potential for improving human health.

Table 3: Bioactive compounds in fresh turmeric and its powder form.

Tumeric	Phenolic compounds (mg GAE g^{-1})	Vitamin C (mg 100 g^{-1})	Flavonoids (mg 100 g^{-1})	Anthocyanins (mg 100 g^{-1})
FS	485.34 ± 43.08	9.33 ± 2.89	179.33 ± 1.17	165.56 ± 0.82
CS	375.72 ± 25.77	8.67 ± 2.31	165.56 ± 0.82	130.31 ± 0.13

*The data represents the mean ± standard deviation of triplicates.

As shown in the table, the values of vitamin C, flavonoids, phenolic, and anthocyanin compounds in the FS were larger than those found in the CS. This may occur due to the weight loss linked to exposure to the external environment (air, light, time, and temperature). These losses may occur at any moment from transportation until arrival for analysis [33].

Regarding phenolic compounds, the values found in saffron were considered excellent both in its fresh and commercial samples, which proved to be rich in phenolic compounds when compared to garlic (*Aframomum danielli* K. Schum) and nutmegs (*Monodora mystica*), other known food seasonings in the studies of Nwankwo (2018) [34], which displayed much lower quantities of phenolic compounds. When compared to other *Curcuma Longa* varieties, such as Kopil Mon

Mura, Kopil Monu Chora, Chittagong Mura, and Chittagong chora, all common in Bangladesh, Southern Asia, it was possible to observe values of phenolic compounds lower than 16.07 ± 0.301 mg GAE g^{-1} [35].

A type of food that is rich in phenolic compounds shows great potential for health because vegetables possessing this constituent contribute to functional quality and play a significant role as free radical scavengers, helping to minimize oxidative cell damage. The health benefits of phenolics are mainly derived from their potential antioxidants because the radicals produced after the donation of hydrogen or electrons are stabilized through resonance and, therefore, are relatively stable. To combat the potential risks of oxidative damage, dietary ingestion of antioxidants such as vitamin C and these compounds, including phenolic acids and flavonoids, are one of the main lines of defense for immunity, so the ingestion of food that is rich in these compounds can be interesting for disease prevention and, as an adjunct, for its treatment [35].

The vitamin C found in the fresh turmeric saffron (CS) had greater results than the commercial sample, INS. Because it is a water-soluble substance, Vitamin C is very sensitive to heat and oxidation, and the destruction of ascorbate is exclusive to each food, varying greatly according to water activity. In this sense, the processing, the presence of external factors, and the period of exposure to them may influence results [36].

In addition, the plantation site is also an interesting factor that changes ascorbic acid results. The works of Tanvir et al. (2017) [35] evaluated the saffron of the land cultivated in different places in southern Asia and had a difference from 0.03 to 0.11 mg 100^{-1} g for each cultivated location. In addition, fertilization can also influence the amount of vitamin C, as analyzed in the studies of Osorio et al. (2019) [26]. Ascorbic acid extracted from turmeric cultivated in plantations that used fertilizers and ones that did not use it was analyzed, and it was noted that antioxidant activity is much better in turmeric grown in soils with organic fertilization and without the use of pesticides beyond conventional soils. In addition, the industrial process of obtaining saffron powder may have caused the lower activity power of commercial turmeric due to the loss of some of the antioxidant compounds, such as ascorbic acid.

When we deal with other rhizomes such as African arrowroot (*Canna indica*), with a value of 11 mg/100g of vitamin C, we observe higher values and can demonstrate that both CS and FS have values below those commonly found in the rhizomes [37]. Thus, it is a rhizome considered to have a low amount when compared to other rhizomes; however, it is possible to increase this amount by observing the ways of processing and exposing it.

Regarding flavonoids, it is possible to observe that commercial saffron presented lower values than its fresh equivalent, given that, like vitamin C, flavonoids may also be subject to losses due to the product's exposure and drying process. This is consistent with the studies of Chumroenphat et al. (2019) [38], which analyzed fresh turmeric, lyophilized, in dry air, sun-dried, and noticed a diminishment according to the drying method, in addition, in fresh saffron the result was 173.82 ± 0.14, which approaches the values of *in natura* saffron. The sample that presented smaller losses during the drying process was the lyophilized one, which presented values of 158.79 ± 0.76 which approaches the values of its commercial equivalent.

Compared to other species of turmeric, such as *Curcuma caesia* and *Curcuma beloved* we observe that the studied samples contained higher values of flavonoids than the two other species, being evident that these species can bring different values of this bioactive compound [39]. In addition, the planting site can also influence its amount of flavonoids. The studies of Tanvir et al. (2017) [35] analyzed turmeric planted in different places and reported a significant difference for rhizomes originating from each planting site, which may also explain the difference in the flavonoid results of the two samples.

Regarding anthocyanin, it was found that *in natura* samples of saffron presented higher values than the commercial samples when compared to other foods, such as white rice, which contains 41.03 ± 3.17 mg 100 g^{-1}. The addition of saffron when cooking rice can be a great alternative to increase the general population's daily consumption of anthocyanins, given that anthocyanin is also a type of antioxidant, which is known as a plant-derived bioactive compound, thus promoting health, slowing the aging process and preventing disease. As a result, antioxidant constituents in plant material awakened the interest of scientists, food manufacturers, cultivators, and consumers due to the role they play in maintaining human health [35-41].

Table 4: Carotenoid values observed in fresh and commercial powder saffron.

Tumeric	Carotenoids		
	Zeaxantine g^{-1}	α-Carotene g^{-1}	β-carotene g^{-1}
FS	180.29 ± 24.43	574.41 ± 42.81	41.88 ± 3.76
CS	131.32 ± 16.31	557.27 ± 41.34	35.49 ± 5.00

*Data represent mean ± standard deviation of triplicates.

Although carotenoids are widely distributed in fresh saffron systems, analyses have only focused on some compounds that are involved in aspects of human health, considering that in biological systems – especially the human system – they behave as antioxidants and pro-oxidants, under different conditions; besides, α-carotene and β-carotene are precursors of retinol biosynthesis (vitamin A). Observing table 4 we can identify that in all the analyzed saffron samples presented higher carotenoid levels in the fresh sample than in the commercial one. However, the values are not far from each other. But when searching for a food with greater nutritional potential and all the benefits of bioactive compounds, the *in natura* saffron is at an advantage [42].

This loss or alteration of carotenoids observed in the commercial saffron may occur during processing and storage and owe to thei being compounds that are highly unsaturated, due to geometric isomerization and enzymatic and non-enzyme oxidation [43]. Preventive measures should be taken to ensure maximum carotenoid retention. But since it is a seasoning condiment, in other studies reported by Rozan (2017) [44], it was possible to note that a carrot jam that used 0, 2, 4, and 6 grams of saffron, there was a change in the sample of 5.91 ± 0.06, 6.534 ± 0.04, 6.746 ± 0.07, 6.831 ± 0.07 β-carotene and 2.041 ± 0.04, 2.683 ± 0.05, 2.794 ± 0.05, 2.822 ± 0.03 of α-carotene, measured in mg 100^{-1} g FW respectively. This demonstrates that saffron can have great potential to enrich foods with carotenoids, as well as add flavor and aroma to it.

There are still no recommendations for the daily consumption of carotenoids for human health, given that their lack does not cause health problems. However, studies show that ingesting 7.4 mg/day of carotenoids has a great relation to seric response in adults. In this context, daily consumption of grams of this condiment can help in obtaining these daily compounds through a balanced and adequate diet [45].

3.4 Analysis of chemical groupings by infrared spectroscopy with Fourier transformation (FTIR) of SF powder

The FTIR spectrum of dry turmeric powder shows spectral peaks with absorption bands in high-frequency bands with variations in intensity, with prominent peaks 3395 cm^{-1} related to stretching vibrations of -OH groups present in cellulose membranes and in water [46, 47], a discrete 2922 cm^{-1}peak, related to stretching bending of the methylene group (-CH2) components of materials rich in hemicellulose carbohydrate components (Figure 1).

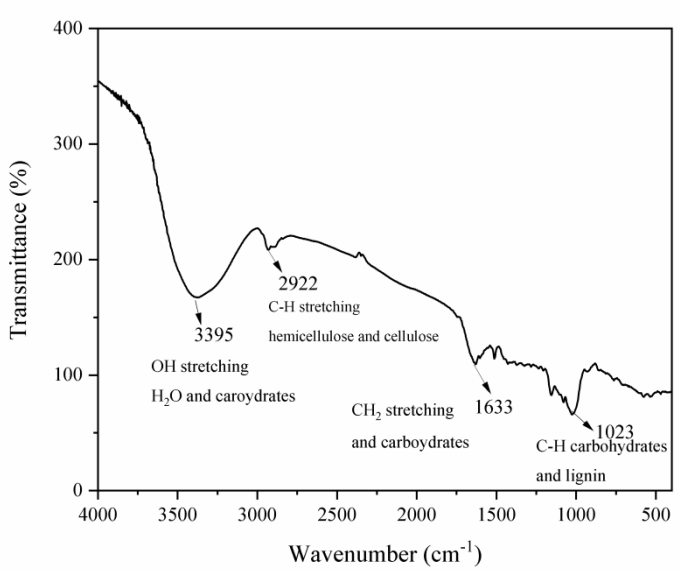

Figure 1: FTIR standard of the sample.

Other bands ranging from 1633 cm^{-1} to 1023 cm^{-1} are present with poor intensity, being characteristics of the carbonyl group of protein amides, found in propeller-shaped structures deformed in the n-h stretch of the carbonyl amide, methyl esters, ketones with flexion of aliphatics groups CH_2 and CH_3 (- - C -H), respectively [46, 47].

The highlight is given to prominent bands 1023 cm^{-1}, which are characteristic of the presence of functional groups carbonyl (C-O), esters, ethers, and carboxylic acids. They are maintained in industrial and laboratorial scale drying processes.

3.5 Morphological analysis of SF powder

Figure 2 presents an overview of the granules resulting from the drying of saffron powder. It is possible to verify the presence of amiloplast-type disordered organelles, constituting the outermost part of the micrography, a non-pigmented structure specialized in synthesizing starch via polymerization of glucose molecules, storing them in the form of starch granules (starchy) these granules have irregular contours and a domed basis.

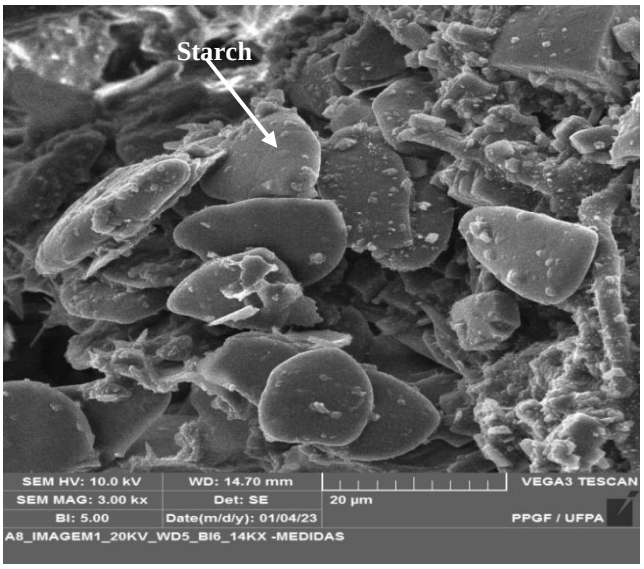

Figure 2: Structure of saffron powder granules.

The presence of stringy-shaped bundles within these wrinkled structures with coupled starch granules may indicate other functions beyond the energetic one, for starches that participate in this type of junction are considered to be resistant, and perform fiber-like functions [48, 49].

4. CONCLUSION

Turmeric has displayed a high potential of bioactive compounds with emphasis on phenolic and α-carotene compounds, given that they are interesting for human health and act to aid the treatment of non-transmissible chronic diseases. By comparative analysis, it was observed that there isn't a very significant amount of bioactive compounds in larger levels in fresh saffron when compared to its commercial equivalent, in view of the physical aspects and the aspects related to the processing and the possible seasonal changes to obtain the rhizome, such as time, temperature, light, among others that can influence this loss during the process of obtaining the powder until its arrival to consumers, so, for the consumer who seeks the better way of obtaining bioactive compounds it would be more interesting to turn to *in natura* turmeric in a powder form. Regarding FTIR spectrum analysis, the samples presented no differences in the major chemical groups. Finally, morphological analysis showed the presence of starches that act on the energy function and on the bundle-shaped fibrous structures which can act in similar functions to those of the fibers.

Regarding the analysis of the FTIR spectrum, the saffron sample dried in the laboratory showed the presence of functional groups related to starches and proteins, emphasizing groups related to cellulose and hemicellulose, which are vegetable energy sources. Finally, the morphological structure of the granules confirms the FTIR data, as they show the presence of starch granules coupled together, which may indicate other functions in addition to energy since the starches that participate in this type of junction are considered resistant and perform functions similar to those of the fibers.

5. REFERENCES

1. Teles AM, Rosa TS, Mouchrek AN, Silva AL, Calabrese KS, Souza AF. Cinnamomum zeylanicum, Origanum vulgare, and Curcuma longa essential oils: Chemical composition, antimicrobial and antileishmanial activity. Evidence-Based Complementary and Alternative Medicine. Hindawi. 2019 Jan 15;2019:1-12. doi: 10.1155/2019/2421695
2. Akhondzadeh S, Mostafavi SA, Keshavarz SA, Mohammadi MR, Hosseini S, Eshraghian MR. A placebo controlled randomized clinical trial of Crocus sativus L. (saffron) on depression and food craving among overweight women with mild to moderate depression. PMID. 2020 Feb;45(1):134-43. doi: 10.1111/jcpt.13040
3. Cortez MV, Perovic NR, Soria EA, Defagó MD. Effect of heat and microwave treatments on phenolic compounds and fatty acids of turmeric (Curcuma longa L.) and saffron (Crocus sativus L.). Braz J Food Technol. 2020 Apr;23:e2019205. doi: 10.1590/1981-6723.20519
4. Kocaadam B, Şanlier N. Curcumin, an active component of turmeric (Curcuma longa), and its effects on health. Crit Rev Food Sci Nutr. 2017 Sep;57(13):2889-95. doi: 10.1080/10408398.2015.1077195
5. Tungmunnithum D, Thongboonyou A, Pholboon A, Yangsabai A. Flavonoids and other phenolic compounds from medicinal plants for pharmaceutical and medical aspects: An overview. Medicines. 2018 Aug 5(3):93. doi: 10.3390/medicines5030093
6. Patil SS, Rathod VK. Synergistic effect of ultrasound and three phase partitioning for the extraction of curcuminoids from Curcuma longa and its bioactivity profile. Process Biochem. 2020 Jun;(93):85-93. doi: 10.1016/j.procbio.2020.02.031
7. Oliveira JG, Almeida MJ, Sousa TL, Santos DC, Egea MB. Bioactive compounds of turmeric (Curcuma longa L.). Reference Series in Phytochemistry. 2021 Jul;297-318. doi: 10.1007/978-3-030-44578-2_37-1
8. Alves IPD, Maria ZAJ, Pereira J, Sousa GM, Oliveira TF. Headspace GC/MS for identification of bioactive compounds of *Curmula longa* L. leaf extract: Industrial application as antioxidant for soybean oil. 2023 Apr;47:e013922. doi: 10.1590/1413-7054202347013922

9. Marchi JP, Tedesco L, Melo ADC, Frasson AC, França VF, Wietzikoski Sato S. Curcuma Longa L., o açafrão da terra, e seus benefícios medicinais. Arquivos de Ciências da Saúde da UNIPAR. 2016. Dec;20(3):189-94.
10. Instituto Adolfo Lutz (IAL). Métodos físico-químicos para análise de alimentos. São Paulo: Instituto Adolfo Lutz; 2008.
11. Association of Official Analytical Chemistry (AOAC). Official Methods of Analysis of the Association of Official Analytical Chemistry. 16 th ed. Washington (US): Gaithersburg; 1997.
12. Nagata M, Yamashita I. Simple method for simultaneous determination of chlorophyll and carotenoids in tomato fruit. Nippon Shokuhin Kogyo Gakkaishi. 1992;39(10):925-8.
13. Rodriguez Amaya DB. Aguide to carotenoid analysis in foods. Washington (US): ILSI Press; 2001.
14. Alikbarian B, Casazza AA, Perego P. Valorization of olive oil solid waste using high pressure-high temperature reactor. Food Chem. 2011 May;128(3):704-10. doi: 10.1016/j.foodchem.2011.03.092
15. Lees DH, Francis FJ. Standardization of pigment analyses in cranberries. Hortscience.1972;7(1):83-4
16. Association of Official Analytical Chemistry (AOAC). Official Methods of Analysis of the Association of Official Analytical Chemistry. 18 th ed. Washington (US): Gaithersburg; 2010.
17. Silvio VM, Farias LB, Medeiros JS, Santos LS, Leão PT, Oliveira LA. Parâmetros físicos e químicos do açafrão e uso como corante em iogurte grego saborizado com geleia de maracujá. RSDJ. 2020 Mar 31;9(5):1-19. doi: 10.33448/rsd-v9i5.3244
18. Lazaro LA, Petry C. Produção orgânica de Zingiber officinale com rizomas de diferentes tamanhos e idades. SBPMed. 2022 Jan;21:300-7.
19. Basavaraj P, Jayan PR. Biometric and engineering properties of ginger rhizome towards the development of root crop harvester. Int J Chem Stud. 2020 Jan;8(3):725-30. doi: 10.22271/chemi.2020.v8.i3i.9290
20. Gouvea IFS, Maciel MPR, Carvalho EEN, Boas BMV, Nachtigall AM. Caracterização física e química de farinha de talo de beterraba. Braz J Food Technol. 2020 Mar;6(3):15814-23. doi: 10.34117/bjdv6n3-452
21. Agência Nacional de Vigilância Sanitária (Anvisa). Guia orienta sobre prazos de validade de alimentos. Gov.br [Internet]; 2022 Jul 04 [updated 2022 Nov 03; cited 2023]. Available from: https://www.gov.br/anvisa/pt-br/assuntos/noticias-anvisa/2018/guia-orienta-sobre-prazos-de-validade-de-alimentos
22. Brasil. Ministério da Saúde, Agência Nacional de Vigilância Sanitária (ANVISA). Resolução – RDC nº 716, de 01 de julho de 2022. Dispõe sobre os requisitos sanitários do café, cevada, chás, erva-mate, especiarias, temperos e molhos. Brasília (DF): Diário Oficial da União; 06 Jul 2022. Disponível em: http://antigo.anvisa.gov.br/documents/10181/2718376/RDC_716_2022_.pdf/9c7579a7-9e06-4f64-9d6c-c5a224a73edc
23. Fernando AJ, Gunathunga C, Brumm T, Amaratunga S. Drying turmeric (Curcuma longa L.) using far-Infrared radiation: Drying characteristics and process optimization. J Food Process Eng. 2021 Jun;44(9):13780. doi: 10.1111/jfpe.13780
24. Saha G, Sharangi AB, Upadhyay TK, Al-Keridis LA, Alshammari N, Alabdallah NM. Dynamics of drying turmeric rhizomes (Curcuma longa L.) with respect to its moisture, color, texture and quality. Agronomy. 2022 Jun 13;12(6):1420. doi: 10.3390/agronomy12061420
25. Eze, CM, Aremu, KO, Nnamani, CL, Omeje, PC, Omelagu, CA, Okonkwo, TM. Effect of the incorporation of graded levels of turmeric (Curcuma longa) on different qualities of stirred yoghurt. Afr J Food Sci. 2020 Apr;14(3):71-85. doi: 10.5897/AJFS2020.1903
26. Osorio JR, Correa DPN, Zuñiga O, Andica, RAS. Determination of nutritional value of turmeric flour and the antioxidant activity of Curcuma longa rhizome extracts from agroecological and conventional crops of Valle del Cauca-Colombia. Rev Colomb de Química. 2020 Jan 49(1):26-32. doi: 10.15446/rev.colomb.quim.v1n49.79334
27. Ajayi O, Bankole T. Preservative effects of ginger (Zingiber officinale), tumeric (Curcuma longa) extract and citric acid and pasteurization on the nutritional quality and shelf life of tiger-nut non-dairy milk. J Food Technol Res. 2020 Jan;7(2):202-11. doi: 10.18488/journal.58.2020.72.202.211
28. Silva F, Oliveira S, Silva J, Soares F, Lima R. Análise física, físico-química, química e antioxidante do gengibre (Zingiber Officinale Roscoe) e cristais de gengibre. In: De Oliveira RJ, organizador. Extensão rural em foco: Apoio à agricultura familiar, emprendedorismo e inovação. 1nd ed. São Paulo: Científica; 2020. p. 85-89. doi: 10.37885/200600401
29. Castro DS, Oliveira TB, Lemos DM, Rocha AT, Almeida RD. Efeito da temperatura sobre a composição físico-química e compostos bioativos de farinha de taro obtida em leito de jorro. Braz J Food Technol. 2017 Apr;20:1-5. doi: 10.1590/1981-6723.6016

30. Adefegha SA, Oboh G, Oluokun OO. Food bioactives: the food image behind the curtain of health promotion and prevention against several degenerative diseases. Stud Nat Prod Chem. 2022;72(11):391-421. doi: 10.1016/B978-0-12-823944-5.00012-0
31. Saraiva BR, Vital ACP, Anjo FA, Cesaro E, Matumoto-Pintro PT. Valorização de resíduos agroindustriais: fontes de nutrientes e compostos bioativos para a alimentação humana. Pubsaúde. Oct 2018;1(1):1-10. doi: 10.31533/pubsaude1.a007
32. Barros DM, Silva AF, Moura DF, Barros MC, Pereira AS, Melo MA. A influência da transição alimentar e nutricional sobre o aumento da prevalência de doenças crônicas não transmissíveis. Braz J Food Technol. 2021 Jul;7(7):74647-64. doi: 10.34117/bjdv7n7-579
33. Santos NC, Barros SL, Almeida RLJ, Monteiro SS, Nascimento APS, Silva VMA. Avaliação da degradação dos compostos bioativos do fruto physalis (P. peruviana) durante o processo de secagem. Res Soc Dev. 2020 Jan 1;9(1):1-21. doi: 10.33448/rsd-v9i1.1678
34. Nwankwo PO. A comparative study of the phytochemical constituents, proximate and mineral compositions of Zingiber officinale, Curcuma longa, Aframomum sceptrum and Monodora myristica. Niger Agric J. 2018 Set;49(2):22-5.
35. Tanvir EM, Hossen MdS, Hossain MdF, Afroz R, Gan SH, Khalil MdI, Antioxidant Properties of Popular Turmeric (Curcuma longa) Varieties from Bangladesh. J Food Qual. 2017 May;2017:1-8. doi: 10.1155/2017/8471785
36. Caritá AC, Fonseca SB, Shultz JD, Michniak-KB, Chorilli M, Leonardi GR. Vitamin C: One compound, several uses. Advances for delivery, efficiency and stability. PMID. 2020 Feb;24:102117. doi: 10.1016/j.nano.2019.102117
37. Ayusman S, Duraivadivel P, Gowtham HG, Sharma S, Hariprasad P. Bioactive constituents, vitamin analysis, antioxidant capacity and α-glucosidase inhibition of Canna indica L. rhizome extracts. Food Biosci. 2020 Jun;35:1-11. doi: 10.1016/j.fbio.2020.100544
38. Chumroenphat T, Somboonwatthanakul I, Saensouk S, Siriamornpun S. Changes in curcuminoids and chemical components of turmeric (Curcuma longa L.) under freeze-drying and low-temperature drying methods. Food Chem. 2021 Mar;339:128121. doi: 10.1016/j.fbio.2020.100544
39. Yadav M, Saravanan KK. Phytochemical analysis and antioxidant potential of rhizome extracts of Curcuma amada roxb and Curcuma caesia roxb. JDDT. 2019 Oct;9(5):123-6. doi: 10.22270/jddt.v9i5.3609
40. Ratseewo J, Warren FJ, Siriamornpun S. The influence of starch structure and anthocyanin content on the digestibility of Thai pigmented rice. Food Chem. 2019 Nov;(298):124949. doi: 10.1016/j.foodchem.2019.06.016
41. Oliosi G, Rodrigues JDO, Falqueto AR, Pires FR, Monte JA, Partelli FL. Fluorescência transiente da clorofila a e crescimento vegetativo em cafeeiro conilon sob diferentes fontes nitrogenadas. Coffee Sci. 2017 Jun 4;12(2):248.
42. Rosário VNM, Chaves RPF, Pires IV, Santos Filho AF, Toro MJU. Capsicum annuum e Capsicum chinense: características físicas, físico-químicas, bioativas e atividade antioxidante. Braz J Dev. 2021 set;7(5):50414-32.
43. Rodriguez-Amaya, D. B. Carotenoids and food preparation: The retention of provitamin A carotenoids in prepared, processed and stored foods. Arlington (VA): John Snow Incorporated/OMNI Project; 1997.
44. Rozan, M. Carotenoids, phenolics, antioxidant activity and sensory attributes of carrot jam effect of turmeric addition. Egypt J Food Sci. 2017 Aug;(45):113-23
45. Böhm V, Lietz G, Olmedilla-Alonso B, Phelan D, Reboul E, Bánati D. From carotenoid intake to carotenoid blood and tissue concentrations – implications for dietary intake recommendations. Nutrition Reviews. 2020 Aug;79(5):544-73. doi: 10.1093/nutrit/nuaa008
46. Najeeb MI, Sultan MTH. Structural health monitoring: Sensing device technology in recent industrial applications. In: Jawaid M, Hamdan A, Sultan MTBH, editors. Structural Health Monitoring System for Synthetic, Hybrid and Natural Fiber Composites. 1nd ed. Singapore: Springer; 2021. p. 1-8. doi: 10.1007/978-981-15-8840-2_1
47. Santos OV, Cunha NSR, Duarte SPA, Soares SD, Costa RS, Mendes PM, et al. Determination of bioactive compounds obtained by the green extraction of taioba leaves (Xanthosoma taioba) on hydrothermal processing. Food Sci Technol. 2022 Jun;42:e22422. doi: 10.1590/fst.22422
48. Jefferson A, Adolphus K. The effects of intact cereal grain fibers, including wheat bran on the gut microbiota composition of healthy adults: A systematic review. Front Nutr. 2019 May;(6):22422. doi: 10.3389/fnut.2019.00033
49. Tosh SM, Bordenave N. Emerging science on benefits of whole grain oat and barley and their soluble dietary fibers for heart health, glycemic response, and gut microbiota. Nutri Rev. 2021 Aug 1;(78):13-20. doi: 10.1093/NUTRIT/NUZ085