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ORIGINAL ARTICLE

Nutritional and functional compounds in dahlia flowers and roots

Compostos nutricionais e funcionais em flores e raízes de dália

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Abstract

The use of unconventional edible plants in human food has grown more widespread in recent years, driven mainly by gourmet dishes. Evidence of the food properties of these species is still scarce. Aiming to obtain more in-depth knowledge of dahlia plants, this study aimed to evaluate the nutritional, bioactive, and antinutritional properties of the edible parts of purple dahlia (tuberous root and flower) to elucidate their value and safety as foods. The percent composition, caloric value, pH, Total Soluble Solids (TSS), Total Titratable Acidity (TTA), ratio of TSS to TTA, anthocyanins, carotenoids, vitamin C, total phenolics, tannins, nitrates, and minerals of the roots and flowers were analyzed. The inulin content in the root and the color of the flower were also evaluated. The results were reported as mean and standard deviation, and exploratory factor analysis was performed. Both parts of the dahlia had constituents that contribute to a good diet at concentrations like those in conventional vegetables, whereas the antinutritional components were also compatible with those of commonly consumed foods, with acceptable dietary values. Thus, it is evident that purple dahlia flowers and roots have potential for use in human food and can be considered good options to improve and diversify a healthy diet.

Keywords: *Dahlia* spp.; Bioactive compounds; Percent composition; Nutritional composition; Antinutritional compounds; Edible flowers.

Resumo

A utilização de plantas alimentícias não convencionais na alimentação humana tem crescido nos últimos anos, impulsionada principalmente pelos pratos gourmet. Entretanto, estudos comprovando as propriedades alimentícias destas espécies ainda são incipientes. Sendo assim, objetivou-se com este trabalho avaliar as propriedades nutricionais, bioativas e antinutricionais das partes comestíveis da dália roxa (raiz tuberosa e flor), para elucidar seu potencial e a segurança no seu consumo. Foram, dessa forma, analisados: composição centesimal, valor calórico, pH, sólidos solúveis totais, acidez total titulável, ratio, antocianinas, carotenoides, vitamina C, fenólicos totais, taninos, nitratos e minerais para a raiz e a flor, além da avaliação do teor de inulina na raiz. Os resultados foram analisados pelas médias e desvio padrão, e foi realizada a análise fatorial exploratória. Ambas as partes avaliadas possuem constituintes requeridos para uma boa alimentação em concentrações semelhantes às das hortaliças convencionais, enquanto os componentes antinutricionais também são compatíveis aos de alimentos comumente consumidos, com valores aceitáveis na alimentação. Desse modo, é evidenciado que flor e raiz de dália roxa apresentam potencial para uso na alimentação humana, podendo ser consideradas como boas opções para incrementar e diversificar uma dieta saudável.

Palavras-chave: *Dahlia* spp.; Compostos bioativos; Composição centesimal; Composição nutricional; Compostos antinutricionais; Flores comestíveis.

Highlights

- The studied parts of dahlia showed constituents required for good nutrition.
- The levels of antinutritional molecules were like those of commonly eaten foods.
- Dahlia flowers and roots have potential for fresh consumption or as raw material for processed foods.

1 Introduction

Dahlia (*Dahlia* spp.) is a genus belonging to the family Asteraceae that is widely used for ornamental purposes as a potted plant or cut flower. It is native to Mexico, where, in addition to its ornamental value, it is a source of food and medicines. Its tuberous roots and petals are consumed and used in different gastronomic elaborations (Lara-Cortés et al., 2014) and for medicinal purposes. Its tuberous root is indicated for diabetic patients because it helps to regulate blood glucose levels, in addition to decreasing cholesterol and triglycerides (Mejía-Muñoz et al., 2020). Petals have a long history of consumption by the indigenous population in the form of small cakes, and even today this species is consumed in salads, in desserts, and as a garnish in many dishes (Treviño et al., 2007). In Brazil, dahlia petals are used only for ornamental purposes, where there is a wide diversity of types and colors.

Dahlia's tuberous roots and flowers have potential as functional, medicinal, and gastronomic foods. Its tuberous roots have a high content of carbohydrates, including inulin and fibre, proteins, vitamins, minerals, and bioactive compounds that can benefit human health (Lara-Cortés et al., 2014; Ciobanu et al. 2016; Rivera-Espejel et al., 2019). Inulin has been widely used in the food industry as a supplement, as a substitute for macronutrients, and also as a substrate for probiotics. Dahlias are included among plant species with high levels of inulin (Hughes, et al., 2017).

Its flowers also have high concentrations of bioactive compounds and a healthful nutritional composition, so they can be consumed as fresh products, as evidenced by Espejel et al. (2019). These authors analyzed the physicochemical properties, nutritional value, and antioxidant capacity of flowers of dahlia species and confirmed the high concentrations of these compounds in the flowers. A similar study was conducted by Lara-Cortés et al. (2014), who detected compounds such as carotenoids and anthocyanins, in addition to finding that the flowers and roots were more than 80% of water, making them a low-calorie food. Therefore, dahlias can contribute not only to the decor but also to the flavor of culinary dishes, by adding nutritional value to the human diet. Lara-Cortés et al. (2014) reported that purple dahlia flowers are an important source of compounds with biological activity, such as antioxidants, making them a functional food.

It is important to know the physicochemical composition of edible flowers, since some species may have phytotoxic compounds in their flowers (Newman & O'Connor, 2009). The petals are the parts that are usually consumed, and other parts of the flower may have an unpleasant taste and even cause allergic reactions (Mlcek & Rop, 2011). More than 40 compounds have been identified in the roots and shoots of dahlia species, mostly acetylenes that can be toxic (Lam, 1998).

Given the scarcity of studies on the nutritional components and bioactive compounds of dahlias, in addition to the limited knowledge about their suitability as foods, this study aimed to evaluate the nutritional, antinutritional, and bioactive properties of tuberous roots and flowers of *Dahlia* spp.

2 Materials and methods

The plant materials evaluated in this study were taken from the municipality of Itumirim, in the state of Minas Gerais (latitude 21°19′ 01″ S, longitude 44°52′ 15″ W, and altitude 870.56 m). According to the classification by Köppen and Geiger, the climate of the region is subtropical with a dry winter (Cwa), with an average temperature of 20.2 °C and an average annual rainfall of 1,481 mm (Alvares et al., 2013).

Dahlia plants with purple flowers were used. Both their tuberous roots and their flowers were analyzed, and no type of chemical was used in the cultivation. Flowers were randomly collected during the flowering of March 2019. The petals were detached from the receptacle and homogenized. About one-tenth of them were reserved for analysis of the fresh matter, and the rest were put in an air-circulation oven (TECNAL, TE-394/3) at 40 °C to dry until they reached constant weight, after which they were ground with a mortar and pestle for analysis of the dry sample.

The roots were collected after the flowering period (June 2019), and after harvest, the roots were separated from the rest of the plant and washed under running water to eliminate soil and impurities. The samples were peeled and cut in half to facilitate and standardize the process. They were separated into three portions, which were stored in plastic bags and frozen in a conventional freezer at -20 °C. They were later placed in three aluminum trays and sent for lyophilization (Liotop L108 freeze dryer), where they remained at -50 °C under a partial vacuum of 38 μmHg until constant weight. Then, they were ground with a mortar and pestle to be analyzed.

The samples were analyzed for their percent composition and bioactive compounds in the Fruit and Vegetable Postharvest Laboratory and the Grains, Roots, and Tubers Laboratory, both Food Science Department of the Federal University of Lavras (Universidade Federal de Lavras-UFLA). Analyses of minerals were conducted at the Nutrition Laboratory of the Soil Science Department, UFLA.

Both in the flowers and in the roots, the following were evaluated: moisture; ether extract; crude protein; ash; crude fibre; carbohydrate fraction; pH (microprocessed pH meter TECNAL® R-TEC-7-MP);Total Titratable Acidity (TTA),Total Soluble Solids (TSS) (digital refractometer model PAL-1, brand ATAGO), and TSS/TTA ratio according to the Association of Official Analytical Chemists (2012) Analytical Standards; caloric value according to Osborne & Voogt (1978); anthocyanins following Lees & Francis (1972) as adapted by Barcia et al. (2012), with results expressed in milligrams of cyanidin-3-glucoside per 100 grams of sample; total carotenoids following Rodriguez-Amaya (2001); vitamin C by the dinitrophenylhydrazine (2,4-DNPH) method according to Strohecker & Henning (1967); total phenolics by the Folin–Ciocalteau method as detailed by Waterhouse (2002) using 50% methanol and 70% acetone for extraction; tannins by the Folin–Ciocalteau colorimetric method according to Association of Official Analytical Chemists (1990) and Deshpande et al. (1986); nitrates by the colorimetric method of Cataldo et al. (1975); and minerals (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn) by the method for the analysis of elements in plant material described by Malavolta et al. (1997), being the nitrogen determined by the semi-micro-Kjeldahl method and the other minerals quantified in Inductively Coupled Plasma (ICP OES).

In the roots, the inulin content was quantified following the method of Anan'ina et al. (2009). Flower color was analyzed using the Konica Minolta CR-400 colorimeter, calibrated according to the CIE system with measurement of the parameters lightness (L*), angle of inclination (h°), and color purity (chroma, C*) (illuminant D65). These measurements were taken at 10 random points due to the variation of tones in the same flower.

The ether extract, crude protein, crude fibre, ash, carbohydrate fraction, inulin and minerals contents were expressed on a dry basis, and the moisture content, caloric value, pH, TTA, TSS, TSS/TTA ratio, color and anthocyanins contents, total carotenoids, vitamin C, total phenolics, tannins and nitrate were expressed in fresh basis.

The results are reported as mean ±standard deviation, and exploratory factor analysis was performed to analyze the patterns between the variables. The exploratory factor analysis used factor loadings that established the correlations between the original variables and the factors found, so that values in modulus between [0; 0.3) were considered a weak factor load, [0.3; 0.5) low factor loading, [0.5; 0.7) moderate factor loading, [0.7; 0.9) high factor loading, and [0.9, 1.0] strong factor loading. The analyses were performed with the aid of scripts for public use developed in R software (R Development Core Team, 2020) using the MVar package version 2.1.3, applied to normalized data for each variable (Ossani & Cirillo, 2020).

3 Results and discussion

The composition of purple dahlia flowers and roots is shown in Table 1.

Table 1. Composition of purple dahlia flowers and roots: moisture, ether extract, crude protein, crude fibre, ash, carbohydrate fraction, caloric value, pH, Total Titratable Acidity (TTA), Total Soluble Solids (TSS), ratio, inulin, color, anthocyanins, total carotenoids, vitamin C, total phenolics, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, manganese, zinc, tannins, and nitrate.

Constituent[a]	Flowers	Roots
Moisture[b] (g 100 g^{-1})	92.97 ± 0.71	84.70 ± 0.46
Ether extract (g 100 g^{-1})	03.01 ± 0.27	00.83 ± 0.19
Crude protein (g 100 g^{-1})	13.80 ± 0.54	11.66 ± 0.55
Ashes (g 100 g^{-1})	07.19 ± 0.08	06.32 ± 0.08
Crude fibre (g 100 g^{-1})	28.97 ± 3.58	04.36 ± 0.18
Carbohydrate Fraction (g 100 g^{-1})	47.03 ± 4.21	76.83 ± 0.53
Caloric value (kcal 100 g^{-1})[b]	19.02 ±3.07	55.30 ± 2.49
pH[b]	05.34 ± 0.12	05.58 ± 0.05
TTA (citric acid g100 g^{-1})[b]	00.28 ± 0.02	00.20 ± 0.02
TSS (g 100 g^{-1})[b]	05.24 ± 0.91	11.08 ± 0.14
Ratio (TSS/TTA)[b]	18.71 ± 1.26	55.40 ± 5.66
Inulin (g 100 g^{-1})	-	72.48 ±8.97
L*	50.17	-
a*	34.07	-
b*	-5.44	-
c*	34.59	-
h*	351.25	-
Anthocyanins (mg 100 g^{-1})[b]	07.40 ± 0.94	**nd**
Total carotenoids (µ 100 g-1)[b]	01.25 ± 0.26	00.74 ± 0.04
Vitamin C (mg 100 g^{-1})[b]	101.67 ± 3.67	153.68± 2.84
Total phenolics (mg 100 g^{-1})[b]	111.99 ± 9.98	66.74 ± 5.07
Tannins (mg 100 g^{-1})[b]	152.91 ± 7.88	380.94 ± 20.03
Nitrate (mg 100 g^{-1})[b]	56.11 ± 3.14	**nd**
Nitrogen (g kg^{-1})	20.1 ± 0.60	14.70 ± 0.40
Phosphorus (g kg^{-1})	03.51 ± 0.11	04.61 ±0.21
Potassium (g kg^{-1})	43.82 ± 0.16	42.49 ± 1.12
Calcium (g kg^{-1})	02.49 ± 0.12	04.91 ± 0.27
Magnesium (g kg^{-1})	02.00 ± 0.10	01.55 ± 0.09
Sulfur (g kg^{-1})	01.31 ± 0.05	00.99 ± 0.03
Boron (mg kg^{-1})	20.60 ± 0.60	03.59 ± 0.26
Iron (mg kg^{-1})	207.82 ± 1.20	34.77± 0.37
Manganese (mg kg^{-1})	24.39 ± 0.21	12.12 ± 0.46
Copper (mg kg^{-1})	06.67 ± 0.06	05.36 ± 0.06
Zinc (mg kg^{-1})	30.58 ± 0.67	14.59 ± 0.73

[a]Mean values obtained from three replicates on a dry basis, followed by the standard deviations. [b]Wet basis - analysis not performed. nd: not detected.

3.1 Percent composition

The moisture content in the flowers and roots was 92.97 ± 0.71 g 100 g^{-1} and 84.70 ± 0.46 g 100 g^{-1}, respectively. As expected, the roots had a higher dry matter content: 30 g 100 g^{-1}, *versus* 15 g 100 g^{-1} for the flowers. These results corroborate those of dahlia species grown in Mexico obtained by Lara-Cortés et al. (2014) (88 to 92 g 100 g^{-1}) and Espejel et al. (2019) (85.9 to 93.4 g 100 g^{-1}). Similarly, the root moisture content in this experiment corroborates the results obtained by Rivera-Espejel et al. (2019), with a range of 75.62 and 88.71 g 100 g^{-1} for the crop. The control of the moisture content in food is important for upholding its quality, as it affects the shelf life and the microbial quality of the food in addition to influencing the structure, appearance, and chemical and enzymatic reactions that lead to degradation (Souza et al., 2019; Berry, 2012). Thus, humidity tests are one of the most important analyses performed on a food product (Padhan et al., 2020).

The high moisture content, with more than 80% of its mass being water, confirms that this food is calorically low (Lara-Cortés et al., 2014). The energy value observed in the flowers (19.02 ± 3.07 kcal 100 g^{-1}) and in the roots (55.30 ± 2.49 kcal 100 $g^{-1)}$, both on a fresh basis (Table 1), confirms the low-calorie content of this species, including when compared to other species whose flowers and roots are consumed. Pansy flowers (*Viola* × *wittrockiana*) showed energy values between 31 and 52 kcal 100 g^{-1} (Fernandes et al., 2019), Nasturtium flowers showed values between 34.32 kcal 100 g^{-1} and 72.79 kcal 100 g^{-1} (Lima Franzen et al., 2016). The caloric value of roots of dahlia was between that of clones of Leren (*Calathea allouia* (Aubl.) Lindl.) (47.96 to 75.25 kcal 100 g^{-1}), as studied by Marques et al. (2019), who reported that variations in its caloric content may be caused by crop treatment and physiological maturity of the roots.

The glycidic fraction or carbohydrate fraction found in the flowers and roots were 47.03 g 100 g^{-1} ± 4.21 and 76.83 ± 0.53 g 100 g^{-1}, respectively, values lower than those could be observed in other tuberous roots, such as yacón (85 g 100 g^{-1}), purple sweet potato (91 g 100 g^{-1}), and white carrot (87 g 100 g^{-1}). Dahlia roots are rich in reserve carbohydrates (Nsabimana & Jiang, 2011), with their most abundant carbohydrate, inulin, presenting levels ranging from 57.95 to 72.25%, depending on the species (Ciobanu et al., 2016), plant origin, climate, cultivation conditions, root maturity, and storage time after harvest (Baranska et al., 2013). In the present study, an average content of 72.48 (± 8.97) g 100 g^{-1} inulin was detected in the roots, corroborating studies conducted by Rivera-Espejel et al. (2019), who observed a maximum content of 72.25 g 100 g^{-1} in different species. This result proves that the species used is an excellent raw material, *i.e.*, supplier of inulin. The low caloric value observed in this article is related to the predominance of inulin, which has low caloric value (Ohno et al., 2013). Present in many plants, inulin has high biotechnological potential to produce several industrially important products (Lara-Cortés et al., 2014). Inulin is 1.5-2 times sweeter than sucrose, making it highly useful in the food industry due to its nutritional and functional potential (Kaur & Gupta, 2002; Hilman et al., 2021; Giri et al., 2021).

Ether extract calculated on a dry basis was 3.01 ± 0.27 g 100 g^{-1} for flowers and 0.83 ± 0.19 for roots (Table 1). The value of 3.01 ± 0.27 g 100 g^{-1} was inconsistent with the findings of Lara-Cortés et al. (2014) in different dahlia species (0.5 to 1.6 g 100 g^{-1}), though it did agree with those of Rivera-Espejel et al. (2019), who observed values between 1.5 g 100 g^{-1} and 3.4 g 100 g^{-1}. This difference can be explained by the color difference between these flowers because in the ether extract analysis, organic substances such as pigments were also detected, not only the lipid content (Lima Franzen et al., 2016). In the roots, the values were higher than those observed by Rivera-Espejel et al. (2019) in dahlias grown in Mexican territories (0.23 to 0.75 g 100 g^{-1}). Factors such as light intensity, salt stress, nutrient deficiency, and cultivation method can alter lipid metabolism in plants. The low content of ether extract observed is favorable and even required for the use of this root as processed products, such as flours and starches (Bramont et al., 2018).

The protein content was 13.80 ± 0.54 g 100 g^{-1} and 11.66 ± 0.55 g 100 g^{-1} in the flowers and roots, respectively (Table 1). These results were close to the concentrations obtained by Espejel et al. (2019), which ranged from 11.9 to 16.2 g 100 g^{-1} crude protein and varied between different species of dahlias and between differently colored dahlias of the same species. Their purple dahlias had 11.9 g 100 g^{-1} of protein, while we measured 13.80 ± 0.54 g 100 g^{-1}. The protein present in the root exceeded that of crops such as yacón, purple sweet potato, and white carrot by approximately 63%, 61%, and 46%, respectively, thus showing its high nutritional potential (Pacheco et al., 2020). This variation may be related to factors such as soil nutritional status, species analyzed, and time of harvest (Juárez-Rosete et al., 2019).

The fibre content of the flower (28.97 ± 3.58 g 100 g^{-1}) was higher than that reported by Espejel et al. (2019) (9.8 to 14.3 g 100 g^{-1})(Table 1), at least doubling it, which can be considered a positive characteristic because this component is important for improving digestibility in diabetic patients, in addition to reducing blood cholesterol and obesity (Anan'ina et al., 2009). Despite its superiority in relation to other findings, the analyzed flower, on a wet basis, did not meet the requirement to be considered a source of fibre by Ordinance SVS/MS no. 29 of January 13, 1998, which establishes a minimum value of 3 g 100 g^{-1} (solid) to receive this characterization (Brasil, 1998). Higher fibre contents in roots are not attractive to the food industry, as they can compromise processing by retaining starch and hindering grinding processes (Roesler et al., 2008). The value observed (4.36 ± 0.18 g 100 g^{-1}) (Table 1), was comparable to that of Rivera-Espejel et al. (2019) (2.88 to 5.49 g 100 g^{-1}).

The ash contents were 7.19 ± 0.08 g 100 g^{-1} and 6.32 ± 0.08 g 100 g^{-1} for the flowers and roots, respectively (Table 1). These results were much higher than those reported by Nsabimana & Jiang (2011) but like those found in other studies of dahlia (Espejel et al., 2019; Rivera-Espejel et al., 2019). The ash content in the food corresponds to the amount of minerals, and the chemical composition of the soil is one of the factors that most influences the portion of ash in the food because this component is the result of complex interactions between minerals in the soil and in the tissues in the entire plant. Thus, the mineral content of the food is linked to the origin of this product (Pacheco et al., 2020). Most unconventional vegetables have high levels of minerals, often exceeding those commonly consumed (Oliveira et al., 2013).

3.2 Mineral analysis

Minerals, macronutrients, and micronutrients are essential to the diet and are responsible for specific functions in human metabolism. The macronutrients present in the dahlia flowers, in decreasing order, were potassium, nitrogen, phosphorus, calcium, magnesium, and sulfur. The root had the same order except that phosphorus and calcium were switched. The micronutrients in both flowers and roots had the decreasing order of iron, zinc, manganese, boron, and copper, but in the root, the copper content was higher than that in boron. Regarding the roots, their concentrations were much higher than those found by Nsabimana & Jiang (2011) on a dry basis among dahlia clones.

The N content was lower than that in other unconventional vegetables considered protein sources, such as cocoyam (*Xanthosoma sagittifolium* (L.) Schott) (50.2 g kg^{-1}) and *ora-pro-nóbis* (*Pereskia aculeata* Mill.) (34.7 g kg^{-1}) (Oliveira et al., 2013). On the other hand, the K content was like that found in other edible flowers, such as pansy (*Viola*×*wittrockiana*) with 39.608 g kg^{-1} (Rop et al., 2012). This element has important functions, participating in the transmission of nerve impulses, protein synthesis, and other aspects of human physiology (Rop et al., 2012). The studied petals had a copper content close to that of broccoli (6.8 mg kg^{-1}). In contrast, the iron present in the dahlia flower was approximately five times higher than that in broccoli (Llorent-Martínez et al., 2020).

Flowers are generally consumed fresh as salads and, depending on the species, can meet up to 25% of the required minerals demand by the human body (Rop et al., 2012). In addition, by fresh matter, approximately 250 g of dahlia root would supply almost 14% of the recommended daily intake for adults of magnesium (0.42 g) and almost 20% of the minerals phosphorus (0.7 g) and copper (0.9 mg), according to the Agência Nacional de Vigilância Sanitária (ANVISA) Regulation, through document RDC no. 269, of September 22, 2005 (Brasil, 2005), and more recently, by Normative Instruction –Instrução Normativa (IN) no. 75, of

October 8, 2020, which establishes the technical requirements for declaration of nutrition labeling on packaged foods (Brasil, 2020).

The plants produce different substances that are healthful for those who consume them, however, they can produce compounds that are considered antinutritional, such as protein inhibitors, oxalates, tannins, and nitrate. Antinutritional factors may lower the nutritional quality of proteins and interfere with the absorption of nutrients by the body. However, when present in low amounts, some of these compounds can act beneficially, such as antioxidants and anticarcinogens (Benevides et al., 2011; Higashijima et al., 2020).

As shown in Table 1, the dahlia roots had higher tannin contents (380.94 mg 100 g^{-1}) than the flowers (152.91 mg 100 g^{-1}). Tannins (tannic acids) are polyphenolic compounds that add color and astringent flavor to foods. They are among the most numerous and widespread substances in the plant kingdom. They are complex polymers with high molecular weights that are a group of phenolic compounds (Alves et al., 2019). Tannins form complexes with proteins, making them insoluble and inactivating enzymes. They may also be responsible for other detrimental effects to the diet, such as undesirable colors foods caused by enzymatic browning reactions and decreased palatability caused by the astringency that they add food due to precipitation of salivary glycoproteins (Alves et al., 2019).

Although there are reports of the negative effect of tannins on the nutritional value of foods, such as reduced protein digestibility, inhibition of the action of digestive enzymes and interference in iron absorption, in addition to recently, reports of damage to the digestive system and systemic toxic effects associated with consumption of high amounts of this substance, few studies have proved the effects of tannins on human health (Higashijima et al., 2020; Marinho et al., 2016).

When comparing the data obtained in this assay with data reported by other authors, we found that the tannin content in dahlia was like that of other commonly consumed vegetables. The levels observed for fresh leaves of kale, broccoli, and cauliflower studied by Santos (2006) showed approximately 200 to 300 mg 100 g^{-1} of polyphenols in fresh matter, values higher than those observed in the dahlia flower of the present study (152.91 ± 7.88 mg 100 g^{-1}). Seeking measures to reduce this compound in consumption, the same author reported that an alternative is to wash the food in water or saline solution before cooking.

Another plant compound considered antinutritional is nitrate, which is widely used as a source of nitrogen for plant growth. We only detected nitrate in the flowers (56.11 ± 3.14 mg 100 g^{-1}). This value is like that of fresh kale leaves, higher than that of cauliflower, and lower than that of broccoli reported by Santos (2006). There are reports of the nitrate content of some plants with consumable floral structures, such as artichoke (*Cynara scolymus* L.), from the same family as dahlia, which has an extremely low nitrate value (1.6 mg 100 g^{-1}), whereas other plants, such as broccoli and cauliflower, have shown higher values than those found for dahlia, at 101.4 mg 100 g^{-1} and 65.80 mg 100 g^{-1}, respectively (Walker, 1990).

There are reports that plants are responsible for more than 80% of the intake of nitrate by humans; therefore, we should pay attention to the plants we eat to reduce the intake of this substance (Ebrahimi et al., 2020; Xarvier et al., 2018). Caution should be taken regarding this compound in the diet because the body can transform nitrate into nitrite, which can be harmful to human health (Teixeira et al., 2020). In Brazil, there is no specific legislation on the maximum permitted limits or acceptable daily intake for nitrates in plants; since the country follows international regulations (Silva et al., 2018; Araújo et al., 2019). The Scientific Committee for Food establishes a daily dose of 3.65 mg/kg body weight as an acceptable value (Comissao Europeia, 2006). In this case, an adult with a mass of 65 kg, on average, could ingest a maximum of 422.83 grams of fresh dahlia flower petals daily.

3.3 Nutritional composition

The flowers and roots in the present study showed slightly acidic pH values (Table 1). Low pH values may favor the action of degradation enzymes. The citric acid content (titratable acidity) observed for flowers and roots was 0.28 and 0.20, respectively, lower than those found for flowers of the same crop (0.4 to 1.4 g 100 g^{-1} citric acid) (Espejel et al., 2019) and for roots (0.17 to 0.31 g 100 g^{-1} citric acid) (Rivera-Espejel et al., 2019). Low citric acid levels may be related to the low concentration of organic acids in the cultivation environment (Oliveira et al., 2019).

The flower and root had higher TSS (Table 1) than those of Espejel et al. (2019) and Rivera-Espejel et al. (2019) (0.10 to 0.20 g 100 g^{-1} for flower and 4.98 to 9.11 for root). The values found for roots were comparable to those found by Silva et al. (2018) in yacón roots (8.58 to 13.6 g 100 g^{-1}), which belong to the same family. Confirming the more sweet taste of these foods, the TSS/TTA ratio, which is responsible for determining the flavor of the food, was high for both evaluated parts of dahlia (Table 1).Thus, dahlia flowers and roots can be considered attractive food alternatives for industrial use, such as in cake preparations, yogurts, and jams, since high levels of soluble solids can improve their flavor in addition to providing a higher processing yield (Silva et al., 2018).

A key factor in the quality of flowers is color, which has a great influence on the consumption of edible flowers (Lara-Cortés et al., 2016). In the present study, the flowers analyzed had a purple color, with mean C* values of 34.59, h° of 351.25, and L* of 50.17. Lightness is related to the absorption of light wavelengths, low values corresponding to darker colors and higher concentrations of secondary pigments, such as anthocyanins and carotenoids (Espejel et al., 2019).

Substances considered bioactive act in the neutralization of excess free radicals caused by oxidative stress, reducing the risk of chronic noncommunicable diseases, such as cancer, diabetes, obesity, and cardiovascular diseases. Many edible flowers have been recognized for having such substances in their composition (Lara-Cortés et al., 2016). Anthocyanins are the main chromophores that belong to the flavonoid group, and confer red, purple, or blue color to food. Considered natural dyes, they contribute much to the attractiveness of food because appearance is one of the first quality attributes evaluated by the consumer (Khoo et al., 2017). We only found anthocyanins in the flower in this study (Table 1), at levels higher than that obtained in tests for purple dahlia (5.17 mg 100 g^{-1}) but lower than that of cherry-colored dahlia (14.74 mg 100 g^{-1}) (Espejel et al., 2019), which can be explained by the L* values observed in the two studies.

Other important bioactive compounds in foods are carotenoids. The low carotenoid content observed in both the flower and the root under study (Table 1) corroborated the report of Lara-Cortés et al. (2014) that this constituent depends on the color of the food and that orange petal flowers have higher content and may also be present in red flowers.

The dahlia flowers and roots both had vitamin C (Table 1). The flowers showed values close to those observed by Espejel et al. (2019), who found a maximum content of 90 mg of ascorbic acid 100 g^{-1} for the different dahlia species, while the value was high when compared to that of Lara-Cortés et al. (2014) (0.05 mg of ascorbic acid 100 g^{-1}). This difference may have been due to the genotype, the part sampled, and the edaphoclimatic conditions of cultivation, all factors that influence the concentration of ascorbic acid in plants (Rivera-Espejel et al., 2019).The ascorbic acid contents observed in the present study for the dahlia root and flower were higher than those of some fruits and vegetables considered rich in this substance, such as orange (47.3 mg 100 g^{-1}), guava (89.9 mg 100 g^{-1}), strawberry (69.8 mg 100 g^{-1}), and broccoli (43.3 mg 100 g^{-1}) (Tabela Brasileira de Composição de Alimentos, 2020). In addition, according to the Regulation for the Recommended Daily Intake (RDI) of protein, vitamins and minerals, the recommended daily amount of vitamin C is 45 mg (Brasil, 2005); thus, approximately 44 grams of petals or 29 grams of dahlia root would satisfy this need.

The total phenolic content observed for the analyzed flowers (Table 1) was lower than that found for purple dahlia in the literature when calculated by fresh base. In contrast, this content was approximately four times higher than that of red flowers, which difference may be due to the extraction method, since the existing methods for this process are not standardized (Lara-Cortés et al., 2014). In the root, the total phenolic content

(66.74 ± 5.07 mg 100 g^{-1}) (Table 1) corroborated those of Rivera-Espejel et al. (2019) of 60 to 174 mg 100 g^{-1} for the same culture.

The results found for the composition of dahlia, both flower and of the root, are close to those described by TACO (Universidade Estadual de Campinas, 2011) and by Tabela Brasileira de Composição de Alimentos (TBCA) (2020) for some vegetables such as celery, lettuce, almond, potato, and sweet potato (considering the fresh matter), which indicates the possibility of using this plant as a component of a varied and healthy diet.

3.4 Factor analysis

For the exploratory factor analysis, the explanations of the variances attributed to the first two factors were 93.13% and 3.67%, respectively, representing 96.80% of the total variation. Figure 1 shows the magnitude of the variability of all factors found.

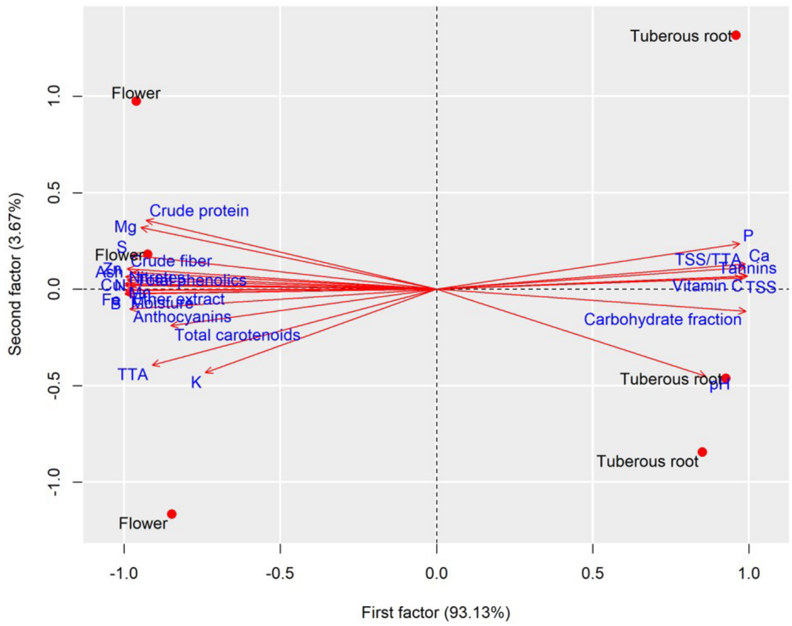

Figure 1. Graph of the magnitude of the variability of the factors found for all variables studied: moisture, ether extract, crude protein, crude fibre, ash, carbohydrate fraction, pH, Total Titratable Acidity (TTA), Total Soluble Solids (TSS), ratio, color, anthocyanins, total carotenoids, vitamin C, total phenolics, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, manganese, zinc, tannins, and nitrate.

The data were highly concentrated around the Y axis, suggesting little variability. Thus, the variables carbohydrate fraction, pH, TSS, TSS/TTA ratio, vitamin C, phosphorus, calcium, and tannins are in opposition to the other variables, and the changes caused in one of these substances were followed similarly by the others in the group. In contrast, these changes were inversely reflected in the other variables. The point cloud of the observations regarding the flower and the tuberous root showed that these parts were separated by the Y axis. The tuberous root stood out for having a greater relationship with the constituents cited, while the flower showed a stronger relationship with the other variables analyzed.

These results corroborated those of Rivera-Espejel et al. (2019), which also observed in dahlia root a negative correlation between TSS and TTA, indicating that changes in the soluble solids content lead to the opposite changes in the acidity of the foods. The same authors also reported a positive correlation between TSS and vitamin C, as was observed in the present study.

Among the bioactive compounds analyzed, vitamin C showed negative correlations with anthocyanins, total carotenoids, and total phenols, which three showed positive correlations with each other. Neto et al. (2018) observed a similar pattern when evaluating the correlation of bioactive compounds in fruits of ambarella (*Spondias dulcis* Parkinson), which are also considered unconventional foods.

The roots were more correlated with the levels of phosphorus and calcium, which showed a positive correlation; that is, the changes between these nutrients were associated. The flowers showed a relationship with most of the evaluated nutrients, which agrees with the report that edible flowers are rich sources of minerals (Rop et al., 2012).

These results are important for understanding the features of the dahlia flowers and roots of the present study. They can facilitate studies to enhance the nutritional value of this vegetable, as long as we take care not to negatively interfere with its flavor or safety of consumption.

4 Conclusions

Both studied parts of dahlia showed constituents required for good nutrition in concentrations like those in vegetables eaten by humans. The levels of molecules considered antinutritional were also like those of commonly eaten foods. Both dahlia flowers and roots have the potential for use in food, either for fresh consumption or as raw material for processed foods.

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