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Physicochemical characterization and bioactive potential in *Dovyalis hebecarpa* Warb fruits

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Abstract
Dovyalis hebecarpa Warb (Ceylon gooseberry) is an important and valuable food source in the diet of several countries worldwide with a potential to positively impact nutritional security. This study aimed to evaluate the physicochemical attributes, bioactive compounds, and antioxidant capacity of *D. hebecarpa* fruits grown in Marechal Cândido Rondon/PR. The following parameters were assessed: fresh weight, longitudinal and transverse length, LD/TD (format index), yield in pulp, peel, and seed, soluble solids, titratable acidity, SS/TA (flavor index), pH, ascorbic acid, total carotenoids, yellow flavonoids, total anthocyanins, total chlorophyll, phenolic compounds, and antioxidant capacity (DPPH and FRAP). The review and results of study on ripe fruits of *D. hebecarpa* in Marechal Cândido Rondon/PR revealed that it contains significant levels of soluble solids (18.25 °Brix), good pulp yield (90.19%), and high levels of ascorbic acid (142.09 mg/100g^{-1} of pulp) and total anthocyanins (94.13 mg/100g^{-1} of peel). This information confirms that the fruits of *D. hebecarpa* can be successfully used for the formulation and development of new products, in addition to the utilization of other parts, such as peels and seeds.

Keywords: Ceylon gooseberry, exotic fruit, postharvest, Salicaceae.

Caracterização físico-química e potencial bioativo em frutos da *Dovyalis hebecarpa* Warb

Resumo
A *Dovyalis hebecarpa* Warb (Groselha do Ceilão) é uma importante e valiosa fonte alimentar na dieta de vários países do mundo com potencial de impactar positivamente na segurança nutricional. Este estudo teve como objetivo avaliar os atributos físico-químicos, compostos bioativos e capacidade antioxidante dos frutos de *D. hebecarpa* cultivados em Marechal Cândido Rondon/PR. Os seguintes parâmetros foram avaliados: peso fresco, comprimento longitudinal e transversal, DL/DT (índice de formato), rendimento em polpa, casca e semente, sólidos solúveis, acidez titulável, SS/AT (índice de sabor), pH, ácido ascórbico, carotenoides totais, flavonoides amarelos, antocianinas totais, clorofila total, compostos fenólicos e capacidade antioxidante (DPPH e FRAP). A revisão e os resultados do estudo dos frutos maduros de *D. hebecarpa* em Marechal Cândido Rondon/PR revelaram que contém teores significativos de sólidos solúveis (18,25 °Brix), bom rendimento de polpa (90,19%) e altos teores de ácido ascórbico (142,09 mg/100g^{-1} de polpa) e antocianinas totais (94,13 mg/100g^{-1} de casca). Essas informações confirmam que os frutos de *D. hebecarpa* podem ser utilizados com sucesso para a formulação e desenvolvimento de novos produtos, além da utilização de outras partes, como cascas e sementes.

Palavras-chave: Groselha do Ceilão, fruto exótico, pós-colheita, Salicaceae.

Introduction

Brazil is the third-largest producer of fruits in the world and the seventh-largest producer of fresh tropical fruits, with an emphasis on native and exotic species of the Atlantic Forest. In recent decades, the interest in fruits with sensory and bioactive properties that can promote health has increased. Thus, some specific native and exotic fruits have been explored because of their potential for fresh consumption and agroindustry (Rotili *et al.,* 2018; Rotili *et al.,* 2021).

Among the exotic fruit crops from the Brazilian flora, *D. hebecarpa* is a lesser-known species that has great nutritional potential, health benefits, and high-value products. However, in Brazil, little is known about the fruit and it is underutilized (Bochi *et al.,* 2015; Rotili *et al.,* 2018; Rotili *et al.,* 2021).

D. hebecarpa is a species native to Asia that is cultivated worldwide but mainly produced in Asian and American countries, including Brazil. The species belongs to the *Salicaceae* family, which reaches 4-6 m in height. Has an attractive appearance that is characterized by its subglobose berries, which are up to 2.5 cm in diameter and purple-brown in color, and pubescent skin when ripe. The thin, bitter rind is covered with short, gray, velvety hairs that are unpleasant in the mouth. The pulp of the ripe fruits is very juicy, acidic, purple-red in color, and encloses 9 to 12 hairy seeds that are approximately 6 mm long (Rinaldi, Villa, Silva, & Yassue, 2017).

The berry of *D. hebecarpa* is poorly utilized after harvest in different farming systems. To add value to the fruits after harvest, studies on the physicochemical characteristics, bioactive compounds, and antioxidant capacity are required (Bochi *et al.,* 2015; Rotili *et al.,* 2018; Rotili *et al.,* 2021).

Considering the relevance of this fruit crop as a nutritional and bioactive source and the few investigations on the phytochemical content of this berry, the physicochemical attributes, bioactive compounds, and antioxidant capacity of *D. hebecarpa* fruits were investigated.

Materials and Methods

D. hebecarpa fruits were harvested in 2019 at the Unioeste Experimental Campus located in Marechal Cândido Rondon/PR (Figure 1), south of Brazil, at an altitude of 420 m, with geographic coordinates of 24°34′0″S and 54°4′0″W of the Greenwich meridian. According to the Köppen classification (Alvares *et al.,* 2013), the climate of this region is Cfa, characterized as humid subtropical, with an annual average rainfall of 1,600 mm and minimum and maximum temperatures of 12 °C and 31 °C, respectively.

Figure 1. *D. hebecarpa* bush (A), its leaves and fruits (B), and fruits suitable for consumption and agro-industrial processing (C) from Marechal Cândido Rondon/PR. (Photos: Daniel Fernandes da Silva).

The fruits were harvested directly from the crown of the trees, according to the harvest index color of the ripe fruit (purple-red coloration from the epicarp). Subsequently, the fruits were transported to the laboratory. Healthy fruits without the presence of lesions or signs of senescence were selected and washed with commercial soap, sanitized with 2% sodium hypochlorite for 15 minutes, and dried with absorbent paper.

The following physical assessments of fruits were performed: fresh weight of the whole fruits (g), obtained by direct reading on a semi-analytical balance (PR224, brand Ohaus); longitudinal and transverse diameter of the whole fruits (mm), determined with a digital caliper (Starrett, model 125MEB, Brazil), 0.05 mm precision; LD/TD (format index) of the whole fruits, established from the ratio between the longitudinal and transverse diameter; and yield of the pulp, peel, and seed of fruits (%) (AOAC, 2016).

The peel and pulp of fruits were manually separated, ground in a domestic multiprocessor, identified and immediately placed in polyethylene bags bottles. They were stored in a freezer at -20 °C for later analysis.

The soluble solids content in pulp of fruits was determined by digital refractometer (model PR-100 Pallete Atago), expressed as °Brix. The titratable acidity in pulp was determined by titration with 0.1 N NaOH solution, expressed as % citric acid. The relation between soluble solids and titratable acidity in pulp was also determined. The pH in pulp was measured using a digital potentiometer (model pH Meter Tec-2) with pH 4 and 7 buffer solutions (AOAC, 2016).

The contents of following bioactive compounds were evaluated: the ascorbic acid level was determined by titration with 2,6-dichlorophenol-indophenol (Dinesh *et al.,* 2015), expressed in mg/100g^{-1} of pulp and peel; total carotenoids (Higby, 1962), expressed in mg/100g^{-1} of pulp and peel; yellow flavonoids and total anthocyanins (Francis, 1982), expressed in mg/100g^{-1} of pulp and peel; total chlorophyll (Bruinsma, 1963), calculated by the equation of Engel and Poggiani (1991), expressed in mg/100g^{-1} of peel; and the phenolic compounds (Swain & Hillis, 1959), expressed in mg GAE/100g^{-1} of pulp and peel.

The antioxidant capacity was determined using a methodology based on the capacity of the extract to capture the 2,2-diphenyl-1-picrylhydrazyl radical (DPPH method) (Rufino *et al.*, 2010), expressed in μmol TE/100g^{-1} of pulp and peel. The antioxidant capacity of each sample was also estimated by the FRAP assay (Thaipong *et al.,* 2006), expressed in μmol TE/100g^{-1} of pulp and peel.

The results were subjected to descriptive statistical analysis to obtain the mean values and standard deviations. For physical characteristics, we considered a statistical design with 20 fruits as replicates. For physicochemical composition, bioactive compounds contents, and antioxidant capacity characteristics, a statistical design with three replicates was adopted. Data were submitted to analysis of variance and means compared by Tukey test at a significance level of 5% probability. The statistical evaluation of the results obtained in postharvest characterization was performed using the computer program variance analysis system SISVAR (Ferreira, 2014).

Results and Discussion

D. hebecarpa fruits had an average longitudinal diameter of 2.17 mm and a transverse diameter of 2.02 mm (Table 1), with an above-oblong shape (1.07), with a fresh weight of 5.42 g. Large and heavy fruits are, however, valued more in fresh market.

Table 1. Physicochemical characteristics of the ripe fruits of *D. hebecarpa* grown in Marechal Cândido Rondon/PR.

Physicochemical Characteristics	Values
Fresh Weight (g)	5.42±0.44
Longitudinal Diameter (mm)	2.17±0.68
Transverse Diameter (mm)	2.02±0.61
LD/TD	1.07±0.57
Yield in Pulps (%)	90.19±1.12
Yield in Peels (%)	8.98±1.03
Yield in Seeds (%)	0.83±0.78
Soluble Solids (°Brix)	18.25±0.71
Titratable Acidity (% citric acid)	2.30±0.45
SS/TA	7.93±0.22
pH	3.24±0.09

Mean values ± standard deviations of fruits from Marechal Cândido Rondon/PR.

The fruit format index is an important physical parameter for fruits. Values close to 1.0 indicate that the fruits have more rounded shapes and above-oblong shapes (Greco *et al.,* 2014). The total percentage of epicarp was 8.98%, totaling 90.19% pulp yield. This information is important because, in the pulping process, the epicarp is not incorporated into the pulp, as it is very hairy (Rotili *et al.,* 2018).

Similar values for the fresh weight, longitudinal and transverse diameter, and yield of constituent parts of the fruits were observed for the *D. hebecarpa* (Bochi *et al.,* 2015; Rotili *et al.,* 2018).

The fruits contained soluble solids of 18.25 °Brix, titratable acidity of 2.30 (% citric acid), SS/TA of 7.93, and pH of 3.24, in conformity with the report of Rotili *et al.* (2018). Bochi *et al.* (2015) evaluated the physicochemical characteristics of *D. hebecarpa* and monitored them for quality. Rotili *et al.* (2021) evaluated the composition, nutritional aspects, and sensory analysis of jams prepared from *D. hebecarpa*.

Studies on the physicochemical characteristics of fruits are required to determine the diversity of fruit size, color, yield, firmness, biomass, and relationship between fruit and edaphoclimatic conditions in plant species (Nascimento *et al.,* 2014).

The soluble solids content and other physicochemical components in fruits are dependent on the ripening stage at which the fruit is harvested and generally increases during ripening by biosynthesis or polysaccharide degradation. The gradual increase in the amount of photoassimilates, sugars and carbohydrates is evidenced in ripe fruits. Acidity is an important attribute of fruits, as it provides an indication of the degree of maturation and ideal harvest point (Nascimento *et al.,* 2014; Tessmer *et al.,* 2014). These characteristics, however, are greatly influenced by environmental factors, including edaphoclimatic conditions, planting location, and crop management.

The SS/TA is considered one of the most practical ways to evaluate fruit flavor. The sugar content and acidity of the fruits directly affect the SS/TA, and it can vary due to environmental factors, cultivation practices, sunlight quality, temperature, and fertilizer type and dosage. This SS/TA is an important indicator of fruit flavor, as it relates the amount of sugars and acids present, providing a good indication of the balance between these two components (Nascimento *et al.,* 2014).

The pH value can be defined as a comparative criterion between fruits. It should be noted that environmental factors, in addition to genetic ones, considerably influence the chemical composition of plant-based food (Nascimento *et al.,* 2014). Not only the variety of fruits leads to variations in the chemical composition of fruits, but also the degree of ripeness before harvest, postharvest ripening, and storage conditions.

Table 2 shows the ascorbic acid, total carotenoids, yellow flavonoids, total anthocyanins, total chlorophyll, and phenolic compounds present of *D. hebecarpa* fruits.

Table 2. Bioactive compounds of the ripe fruits of *D. hebecarpa* Warb grown in Marechal Cândido Rondon, Paraná.

Bioactive Compounds	Values (pulp)	Values (peel)
Ascorbic Acid ($mg/100g^{-1}$)	142.09±0.89	33.22±0.19
Total Carotenoids ($mg/100g^{-1}$)	28.78±0.65	14.49±0.24
Yellow Flavonoids ($mg/100g^{-1}$)	0.83±0.78	0.21±0.14
Total Anthocyanins ($mg/100g^{-1}$)	0.97±0.68	94.13±0.09
Total Chlorophyll ($mg/100g^{-1}$)	ne	89.23±0.21
Phenolic compounds (mg $GAE/100g^{-1}$)	43.10±0.57	25.53±0.11

Mean values ± standard deviations of fruits from Marechal Cândido Rondon, Paraná. ne: not evaluated.

D. hebecarpa fruits are considered as a bioactive source, with high contents of ascorbic acid in pulp (142.09 $mg/100g^{-1}$), total anthocyanins in peel (94.13 $mg/100^{-1}$), and total chlorophyll in peel (89.23 $mg/100g^{-1}$).

Rosso and Mercadante (2007) evaluated the total carotenoid, flavonoids, and anthocyanins contents of *D. hebecarpa* fruits. Biochemical characterization of *D. hebecarpa* by Bochi *et al.* (2015) indicated that the fruits are a source of anthocyanins that have high antioxidant capacity. Rotili *et al.* (2018) investigated the bioactive compounds in *D. hebecarpa* fruits. Rotili *et al.* (2021) evaluated the nutraceutical and bioactive compounds, nutritional aspects, and performed sensory analysis of *D. hebecarpa* jams.

As for bioactive compounds, ascorbic acid is considered a nutritionally important component and can be used as a standard or quality index of foods, in addition to being used to reduce the risk of diseases (Pertuzatti *et al.,* 2014). However, ascorbic acid content can be influenced by several factors, such as genotypic differences, climatic conditions, preharvest, cultural practices, degree of ripeness, methods, and postharvest management.

The carotenoid content in fruits depends on several factors such as genetic variety, stage of maturation, storage, processing, and preparation. Studies indicated that carotenoids have beneficial effects on health, and that the consumption of fruits containing this pigment is strongly associated with a reduced risk of diseases (Rosso & Mercadante, 2007; Rufino *et al.,* 2010).

It should be noted that flavonoids are naturally found in fresh fruits and since they form a potent group of antioxidants. *D. hebecarpa* fruits are characterized by their high content in nutraceuticals, such as phenolic acids, where anthocyanins and flavonoids are the major compounds. These compounds have biological activities in health, protective effects against degenerative chronic diseases, and act as inhibitors of mutagenesis and carcinogenesis. In addition, these compounds are also associated with antiviral, antiallergic, antiplatelet, and anti-inflammatory activities (Bochi *et al.,* 2014; Bochi *et al.,* 2015; Bochi *et al.,* 2015; Morais *et al.,* 2016).

Fruits tend to lose their green color due to chlorophyll degradation. As fruits ripen, they gradually change in color. Chlorophyll is the pigment that gives the plant its characteristic green color. Chlorophyll plays a unique role in the physiology, productivity, and frugality of green plants (Barua *et al.,* 2016).

Pulps of fruits are a source of antioxidant compounds such as phenolic compounds capable of protecting cellular constituents against oxidative damage and, therefore, limiting the risk of various degenerative diseases associated with oxidative stress. The content of bioactive compounds in fruits depends directly on environmental factors such as cultivar, region of cultivation, and degree of ripeness, and the industrial processing itself can affect these characteristics. Experimental studies strongly supported the role of phenolic compounds in the prevention of cancer, diabetes, and neurodegenerative diseases (Bochi *et al.,* 2014; Morais *et al.,* 2016; Rotili *et al.,* 2022).

The antioxidant capacity of *D. hebecarpa* fruits pulps evaluated by FRAP method was higher in acetonic and methanolic extracts, which was 53.05 µmol TE/100g^{-1} (Table 3). Bochi *et al.* (2015) and Rotili *et al.* (2018) conducted a study with *D. hebecarpa* fruits using the DDPH and FRAP evaluation methods, and it proved that free radicals play an important role in many diseases, such as cardiovascular and neurodegenerative diseases, cancer, and diabetes.

Table 3. Antioxidant capacity of the ripe fruits of *D. hebecarpa* grown in Marechal Cândido Rondon, Paraná.

Fruit	Antioxidant Capacity (µmol TE/100g^{-1})	
	DPPH	FRAP
Pulp	20.45±0.30	53.05±1.44
Peel	21.68±0.12	29.99±0.22

Mean values ± standard deviations of fruits from Marechal Cândido Rondon, Paraná.

Antioxidants have attracted increasing attention as potential agents for the prevention and treatment of disease-related oxidative stress. On the other hand, epidemiological studies had revealed that fruit intake has a strong inverse correlation with the risks of the development of many chronic diseases, such as cardiovascular disease, and cancer (Rosso & Mercadante, 2007; Morais *et al.,* 2016).

Conclusion

D. hebecarpa ripe fruits contain significant amounts of soluble solids (18.25 °Brix), and with high pulp yield (90.19%). They are also considered as a bioactive source, with high contents of ascorbic acid (142.09 mg/100g^{-1} of pulp), and total anthocyanins (94.13 mg/100g^{-1} of peel).

Thus, *D. hebecarpa* fruits exhibit the excellent physicochemical and bioactive attributes that merit inclusion along with other foods. This fruit tree is a promising candidate for new crop plantations.

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