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CROP PRODUCTION

Bioactive compounds, antioxidant and physic-chemical characteristics of the dovyalis fruit

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ABSTRACT. The objective of this work was to evaluate the bioactive compounds, antioxidant activity, and physicochemical characteristics of dovyalis fruit to obtain technological knowledge about this fruit when grown under the conditions found in the municipality of Marechal Cândido Rondon, Paraná State, Brazil. Dovyalis fruits from the State University of Western Parana, which was established in 2012, were harvested in March 2016. Dovyalis fruits were collected from several plants and were divided among three lots. After the harvest, were immediately taken to the Post-Harvest Laboratory for evaluation of the antioxidant activity by the DPPH, ABTS and FRAP methods. The physicochemical characteristics of the fruits and the total phenolic compounds, flavonoids, ascorbic acid, anthocyanins, respiration, and fruit color were evaluated. The experimental design was completely randomized, with the study containing three groups and three replicates per group. Dovyalis fruits present high antioxidant capacity and are characterized as acidic fruits, due to the high FRAP activity. Dovyalis fruits have a very attractive color and high acidity, which makes them appropriate for processing. Regarding the antioxidant activity present in the fruit, the most bioactive components are flavonoids and anthocyanins. High ascorbic acid content was observed in mature dovyalis fruits. Dovyalis fruits are considered climacteric.

Keywords: *Dovyalis*; small fruit; anthocyanins; fruit coloration.

Compostos bioativos, atioxidante e características físico-químicas de frutos de doviális

RESUMO. Objetivou-se com o presente trabalho avaliar os compostos bioativos, atividade antioxidante e características físico-químicas de frutos de doviális, a fim de obter conhecimentos tecnológicos a respeito desta frutífera nas condições de Marechal Candido Rondon, PR. Foram colhidos em março de 2016 frutos de doviális provenientes de pomar experimental da Unioeste, instalado em 2012. Os frutos utilizados de doviális foram coletados de diversas plantas, maduros e divididos em três lotes. Após a colheita, os frutos foram imediatamente levados ao Laboratório de Pós-colheita para a avaliação da atividade antioxidante, através dos métodos DPPH, ABTS e FRAP. Também foram avaliadas as características físico-químicas dos frutos de doviális e compostos fenólicos totais, flavonoides, ácido ascórbico, antocianinas, respiração e coloração dos frutos. O delineamento experimental utilizado foi inteiramente casualizados, contendo três grupos e três repetições por grupo. Frutos de doviális apresentam elevada capacidade antioxidante, sendo caracterizados como frutos ácidos, devido ao aumento da atividade de FRAP. Frutos de doviális possuem coloração muito atrativa e alta acidez, destinando-se ao processamento. Para a atividade antioxidante presente no fruto, os mais bioativos são flavonoides e antocianinas. Elevado teor de ácido ascórbico foi observado nos frutos maduros de doviális. Os frutos de doviális podem ser considerados climatéricos.

Palavras-chave: *Dovyalis*; pequeno fruto; antocianinas; coloração de frutos.

Introduction

Fruit consumption has increased nationally and internationally due to an increasing recognition of fruit nutraceutical values (Jacques, Pertuzatti, Barcia, & Zambiazi, 2009). Fruits may contain different bioactive compounds, many of which may have antioxidant capacity. Many complex biochemical reactions are involved during the ripening process, such as the hydrolysis of starch and the synthesis of carotenoids, anthocyanins, and phenolic compounds, in addition to the formation of various volatile compounds. The bioactive compounds constitute a group of heterogeneous compounds resulting from secondary metabolism in the plants, and these compounds can be classified as glucosinolates, carotenoids, or polyphenols, including flavonoids and anthocyanins (Horst & Lajolo, 2011).

The antioxidant capacity of fruits varies according to the contents of ascorbic acid, flavonoids,

anthocyanins, and other phenolic compounds (Saura-Calixto & Goñi, 2006) and can be evaluated by different methods (Sucupira, Silva, Pereira, & Costa, 2012). The fruits, in addition to having phenolic compounds and carotenoids, may also contain vitamin C or L-ascorbic acid, which is a widely distributed water-soluble and thermolabile vitamin (Jacques & Zambiazi, 2011). Dovyalis fruits are considered a good source of vitamin C, since they present on average 120.3 mg 100 g^{-1} of fresh fruit (Silva et al., 2011).

In addition to the bioactive compounds, the respiration and physicochemical characteristics of the fruit are also important aspects. The respiratory intensity indicates the speed with which metabolism in the fruit develops; that is, high respiratory rates are generally associated with a short shelf life, as is the case with strawberry (Cunha Jr, Jacomino, Trevisan, & Scarpare Filho, 2011). Respiration can be affected by intrinsic factors (chemical composition, metabolic activity, fruit size, and moisture) and extrinsic factors (temperature, relative humidity, CO_2, and ethylene concentration), which can accelerate or slow down the respiratory process, thus influencing the shelf life of the product (Andreucetti, Ferreira, Moretti, & Honório, 2007).

The appearance of a fruit is the criterion most used by consumers to evaluate its quality. A quality fruit is one that meets the expectations of different consumer segments regarding its internal and external characteristics (Abreu, Peixoto, Junqueira, & Sousa, 2009). Regarding the physicochemical evaluations of the fruits, several parameters can be adopted, including the weight, length, diameter, shape, color, firmness, soluble solids, pH, and titratable acidity, among others. These characteristics are influenced by agronomic factors, such as edaphoclimatic conditions, cultivar, time and location of the harvest, culture treatments, and post-harvest handling (Borguini, Bastos, Moita Neto, Capasso, & Torres, 2013).

Dovyalis (*Dovyalis hebecarpa* Gardner Warb.) is a fruit species belonging to the family Salicaceae, genus *Dovyalis*, which has 1300 species and originated in southern India or the island of Ceylon, spreading worldwide and adapting to different regions (Borges et al., 2010). The fruits, also known as Ceylon gooseberries, are 2-3 cm in diameter and have 1-3 seeds, an acidic taste, a very attractive red-purplish color, and an excellent pulp yield, in addition to a pleasant taste; these characteristics make this fruit a good choice for processing. When the fruit is harvested, the calyx remains adhered to the fruit, giving an appearance of freshness and giving the fruit an appearance unlike those produced commercially (Silva, Grizotto, Miguel, & Bárbaro, 2011).

Small red fruits have been the target of several studies for presenting excellent sources of bioactive compounds (Carlsen et al., 2010). Other small fruits such as physalis, butia, blackberry, and dovyalis are considered important sources of phenolic compounds and carotenoids; however, little or no literature is available on the presence of phytochemicals. Therefore, the objective of this study was to evaluate the bioactive compounds, antioxidant activity, and physicochemical characteristics of dovyalis fruits to obtain technological knowledge of the fruit when grown under the conditions found in the municipality of Marechal Cândido Rondon, Paraná State, Brazil.

Material and methods

Obtaining and preparing fruit

Dovyalis fruits were harvested in March 2016 from an orchard established in 2012 on the "Prof. Dr. Antônio Carlos dos Santos Pessoa Experimental Farm" (Guará Line), which belongs to the Nucleus of Experimental Stations (Núcleo de Estações Experimentais - NEE) of the State University of the Western Paraná (Universidade Estadual do Oeste do Paraná - Unioeste), municipality of Marechal Cândido Rondon, Paraná State, Brazil. The fruits harvested were from the second crop of fruits.

After harvest, the fruits were selected for uniformity of size, color, and absence of defects. They were subsequently sanitized by immersion in a solution with 0.1 mL L^{-1} sodium hypochlorite for 3 minutes at room temperature and were subsequently dried with paper towels. Fruits with the predominantly dark purple peel color were collected from different plants at the optimum harvest time. Each batch was a blend of completely ripe fruit, harvested from various plants. Three independent lots (approximately 300 g) of fruits were included from the 2016 harvest.

Antioxidant activity

An extract was prepared with the addition of 1.0 mL of juice in 9.0 mL of 80% (v/v) ethanol. Subsequently, the extract was homogenized by vortexing for 30 seconds and then was dispersed (Ultra-turrax) for one minute. The extract was then centrifuged at 2,000 g for 20 minutes. The entire procedure occurred in the dark and was performed in duplicate. Upon completion of the procedure, the extracts were stored at -24°C until analysis.

Antioxidant activity was evaluated according to the capacity of the extract to sequester the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical, based on the method proposed by De Ancos, Sgroppo, Plaza, and Cano (2002). In total, 10 mL of sample and 0.3 mL of DPPH solution (0.5 mmol L^{-1}) were added to 3 mL of ethanol and allowed to rest for 60 minutes in the dark. Subsequently, the absorbance was determined by spectroscopy (Shimadzu, UV-1800, Japan) at 517 nm. The results are expressed in mg 100 g^{-1}, in Trolox equivalents (TE), using a Trolox calibration curve at concentrations of 0.035, 0.03, 0.025, 0.02, 0.015, 0.01, and 0.005 mg.

The ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) method estimates the ABTS radical sequestration ability of the sample and was carried out according to (Rufino et al., 2007). A total of 3 mL of ABTS reagent (5 mL of 7 mM ABTS stock solution plus 88 μL of 140 mM potassium persulfate solution, kept in the dark for 16 hours and diluted in ethanol to an absorbance of 0.700 ± 0.05 nm at 734 nm), was added to 6 mL of the sample. After the sample had been held in a dark environment for 6 minutes, readings were performed at 734 nm (Shimadzu, UV-1800, Japan). The results are expressed in mg 100 g^{-1}, in Trolox equivalents (TE), using a Trolox calibration curve at concentrations of 0.375, 0.325, 0.250, 0.175, 0.125, 0.075, and 0.025 mg.

The FRAP (Ferric Reducing Antioxidant Power) method was performed according to the methodology described by Rufino et al. (2007). In total, 270 μL of distilled water and 2.7 mL of the FRAP reagent (25 mL of 0.3 M acetate buffer, 2.5 mL of 10 mM TPTZ solution and 2.5 mL of 20 mM of ferric chloride aqueous solution) were added to 18 mL of the sample. The solution was maintained at 37°C in a dark environment for 30 minutes, after which a spectrophotometric reading was performed at 595 nm (Shimadzu, UV-1800, Japan) using the FRAP reagent as the blank for equipment calibration. The results are expressed as mg 100 g^{-1}, in ferrous sulfate equivalents (FSE) or Trolox equivalents (TE) g^{-1}, by using a calibration curve for ferrous sulfate at concentrations of 0.125, 0.250, 0.375, and 0.500 mg.

Total phenolic compounds were determined according to George et al. (2005).

An aliquot of 10 mL of sample was added to 2.5 mL of a Folin-Ciocalteu:water solution (1:9 v/v) and 2.0 mL of 7.5% (w/v) sodium carbonate solution. After the solution had been held in a dark environment for 15 minutes, the absorbance was measured by spectroscopy (Shimadzu, UV-1800, Japan) at 760 nm. The results are expressed in mg 100 g^{-1}, in gallic acid equivalents (GAE), using a calibration curve for gallic acid at concentrations of 0.01 to 0.07 mg mL^{-1}.

The phenolic compounds were determined according to Chang et al. (2002), with modifications. In total, 4.3 mL of 80% ethanol in water (v/v), 0.1 mL of $AlCl_3$, and 0.1 mL of potassium acetate were added to 0.5 mL of the extract. A control series was performed in parallel by adding 80% ethanol instead of $AlCl_3$. After 40 minutes in the dark at room temperature, the samples were examined for absorbance, which was measured at 415 nm by spectroscopy (Shimadzu, UV-1800, Japan). The results are expressed in mg 100 g^{-1}, in quercetin equivalents (QE), and calculated by adjusting the calibration curve for quercetin.

Anthocyanins were determined using the differential pH methodology proposed by Lee, Durst, and Wrolstad (2005), where buffer solutions of pH 1 (0.025 M KCl) and pH 4.5 (0.4 M $C_2H_3NaO_2$) were first prepared. Subsequently, 1 mL of extract and 19 mL of the respective buffers were added. After 20 minutes, the absorbance values of both solutions were measured at 510 and 700 nm by spectroscopy (Shimadzu, UV-1800, Japan). Ultrapure water was used as the blank. The total anthocyanins value (AT, mg Ci-3-Gly L^{-1}) was obtained by Equation 1 and is expressed per 100 g of dovyalis.

Equation 1:

$$AT = (A \times MW \times DF \times 10^3) \div (\epsilon \times I)$$

where: $A = (A_{510nm} - A_{700nm})$ pH 1 – $(A_{510nm} - A_{700nm})$ pH 4.5, MW = 449.2 g mol^{-1} for cyanidin-3-glucoside, DF = dilution factor, I = optical path in cm, and E = 26,900 molar extinction coefficient (L x mol^{-1} x cm^{-1}). 10^3 = grams to milligram conversion factor.

Physic-chemical assessments

For the physical characterization of the samples, the means of the lengths (larger diameter) and widths (smaller diameter) were considered, which were determined using a digital caliper, according to IAL (2008); all analyses were performed in triplicate. The mean weight loss was determined by the difference between the final and initial weights and by expressing the results as a percentage. Fruits were weighed on a semi-analytical balance model (AS 5500C). For the determination of moisture, samples of the fruit, peel, and pulp fractions were weighed and oven dried at 65°C until reaching constant weight, according to the methodology of the Official Association of Analytical Chemists (AOAC, 2005).

Soluble solids (SS) content was determined by a direct method, using a digital bench refractometer WYA (model 2WA-J), with results expressed in °Brix.

The titratable acidity (TA) was obtained by titrating 5 mL^{-1} of homogenized juice diluted to 100 mL with distilled water with a standard solution of

0.1 N sodium hydroxide, with phenolphthalein as the indicator. The results are expressed in grams of citric acid per 100 g of pulp (IAL, 2008). The determination of the ratio was performed through the SS/AT ratio, which indicated the equilibrium between the sugars and organic acids of the fruit and represents an important parameter to measure the perception of taste by the consumer.

The determination of the pH was carried out by direct reading from the solutions of juice from the homogenized fruits, with a 50-mL aliquot of the sample being measured with the aid of a pH meter previously calibrated with buffer solutions of pH 4.0 and 7.0. Ascorbic acid was determined by titration with 2,6-dichlorophenolindophenol, as proposed by Benassi and Antunes (1988), with results expressed in mg 100 mL^{-1} of juice.

Fruit firmness was measured using a benchtop digital texturometer (Brookfield, CT3, USA). The whole fruits were placed on a flat surface, and the firmness of each was measured in the fruit's equatorial region. A stainless steel rod with a diameter of 8 mm was used. The test velocity was adjusted to 1.5 mm s^{-1}, with a displacement depth of 10 mm. The results are expressed in Newtons (N).

The fruits were placed in sealed plastic vials with caps containing a silicone septum for gas sampling and determination of respiratory activity (mg CO_2 kg^{-1} h^{-1}). An hour after the vials had been closed, a total of 2.0 mL of the atmospheric gas inside the vials was collected with a Gastight syringe for CO_2 measurement. The collected samples were injected into a gas chromatograph (Finnigan, 9001) calibrated for column (capillary), splitless, detector (flame ionization), and methanator temperatures of 80, 150, 250, and 350°C, respectively. Nitrogen was used as carrier gas, according to the methodology described by Zhu and Zhou (2007).

Fruit color was visually verified at six ripening stages: green fruit (1), green fruit in transition (2), fruit darker than green (3), brown fruit (4), ripe fruit (5), and senescent fruit (6) (Table 1). After visual segregation, the predominant color in the fruit epicarp was described using the Munsell method (Munsell, 1976).

Table 1. Color of dovyalis fruits in the different ripening stages, adapted from Munsell (1976). Unioeste, Campus of Marechal Cândido Rondon, Paraná State, 2017.

Ripening stage	Epicarp color	Visual characterization	Munsell chart
1		Green fruit	2.5 GY 6/6
2		Green fruit in transition	2.5 GY 5/8
3		Darker than green fruit	2.5 YR 4/6
4		Brown fruit	2.5 YR 3/4
5		Ripe fruit	2.5 YR 3/6
6		Fruit in senescence	5.0 YR 3/2

Experimental design and statistical analysis

The experimental design was completely randomized, containing three groups and three replicates per group. The data were subjected to analysis of variance, and when significant, the data were subjected to the Tukey test, at a 5% probability of error, which was performed using the statistical program Sisvar (Ferreira, 2011).

Results and discussion

Table 2 shows the antioxidant compounds (determined with the DPPH, ABTS, and FRAP methods), phenolic compounds, flavonoids, and anthocyanins present in dovyalis fruits. The antioxidant capacities of the fruits were similar according to the DPPH and ABTS methods but differed according to the FRAP method, which showed the highest antioxidant activity.

The methods for assessing the antioxidant activity proposed in the literature are diverse, but some are more appropriate than others depending on the nature of the compounds present in the constitution of each fruit. The methods widely employed in fruits are the sequestration capacity of free radicals, such as ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)), DPPH (2,2-diphenyl-1-picrylhydrazyl), and ferric reducing antioxidant power (FRAP), which were used in the present work. The lack of standardization of methods makes it difficult to compare the published data, mainly due to the use of different solvents and different ways of expressing the results. Similarly, variations in the antioxidant complex of each food may provide different responses from each method (Sucupira et al., 2012). Therefore, a combination of at least three of these methods is needed to provide more complete and representative results of the antioxidant capacity of fruits (Pérez-Jiménez et al., 2008).

The antioxidant activity quantification test using the FRAP method is based on the ability to reduce iron and is not based on free radical sequestration, as in the case of the DPPH expressed in Trolox. In acidic media, iron is reduced, thereby forming a colored compound in the presence of antioxidants, causing an increase in absorbance (Sucupira, 2012). In studies with various fruits *in natura*, Abe, Lajolo, and Genovese (2012) found values of 0.15 mg Trolox g^{-1} in blackberries and 0.62 mg Trolox g^{-1} in jaboticaba. For this same method, values of 4.87mg Trolox g^{-1} were found in the present study, indicating that dovyalis fruits present high antioxidant capacity and are characterized as acidic fruits due to the high FRAP activity.

Table 2. Methods of determination of the antioxidant capacity (DPPH, ABTS, and FRAP methods), phenolic compounds, flavonoids, and anthocyanins of dovyalis fruits. Unioeste, Campus of Marechal Candido Rondon, Paraná State, 2017.

	---------- Methods for determining antioxidant capacity ----------					
	DPPH	ABTS	FRAP	Phenolic compounds	Total flavonoids	Anthocyanins
	mg TE 100 g^{-1}	mg TE 100 g^{-1}	mg ferrous sulfate 00 g^{-1}	mg GAE 100 g^{-1}	mg quercetin 100^{-1}	Mg cyanidin-3-glucoside g^{-1}
Means±SD	17.08 ± 0.68	16.00 ± 1.22	487.13 ± 52.94	4.35 ± 0.07	9.64 ± 0.56	67.36 ± 4.74
CV (%)	3.97	7.61	10.87	1.60	5.76	7.04

TE: Trolox equivalents.

The content of the total phenolic compounds found in dovyalis fruits was 4.35 mg GAE 100 g^{-1} (Table 2). In studies with different fruits *in natura*, Souza et al. (2014) found values (8.51 mg GAE 100 g^{-1} in blackberry; 3.58 mg GAE 100 g^{-1} in red raspberry; 3.05 mg GAE 100 g^{-1} in blueberry and 3.14 mg GAE 100 g^{-1} in cherry) similar to those found in the present study.

For total flavonoid content, a value of 9.64 mg GAE 100 g^{-1} was found. When studying different cultivars of blackberry, Celant, Braga, Vorpagel, and Salibe (2016) observed a content of 9.67 mg GAE 100 g^{-1} in the "Choctaw" cultivar, results that agree with the results of the present work.

Several authors report that the genotype and the environmental conditions are among the factors that cause large variations in the chemical composition of fruits (Cho, Seddon, Rosner, Willett, & Hankinson, 2004). In tropical or subtropical climatic conditions, prolonged periods of severe drought or too much rainfall, high radiation levels, and extreme temperatures cause environmental stress. Such stress can increase the production of the phenolic antioxidants as a plant mechanism to detoxify the cells from high levels of free radicals (reactive oxygen species) produced due to oxidative environmental stress (Celant et al., 2016). This leads to variations in the content of phenolic compounds in species produced in different regions.

Table 2 also shows that the anthocyanins present in the fruits represent 67.36 mg cyanidin-3-glucoside 100 g^{-1}, thus indicating the fundamental role they serve as natural antioxidants. In studies with bioactive compounds in blueberry cv. Delite, Jaques et al. (2009) found values of 72.0 mg of cyanidin-3-glucoside 100 g^{-1} of fruit, values close to those found in dovyalis fruits.

Table 3 shows the results for the physicochemical characterization of the dovyalis fruits. In the present study, the dovyalis fruits had an average length of 2.18 cm and a width of 2.03 cm, presenting a rounded shape and a fresh biomass of 5.43 g. Similar values for the lengths and widths of the fruits were observed for the Tupy blackberry cultivar (Pereira et al., 2009). This knowledge is feasible for determining the diversity of the fruit size, the biomass of each fruit species (Rocha, Figueiredo, Araujo, & Moreira-Araujo, 2013), and the relation of the fruit to edaphoclimatic factors (Nascimento, Cardoso, & Cocozza, 2014). Fruits with good appearance and high measurements are sought for the commercialization and processing of industrialized products (Chitarra & Chitarra, 2005).

Table 3. Physical-chemical characterization of dovyalis fruits. Unioeste, Campus of Marechal Cândido Rondon, Paraná State, 2017.

Physical-chemical assessment	Dovyalis Fruits	
	Average ± SD	CV (%)
Length of the fruit (cm)	2.18 ± 0.70	3.21
Width of the fruit (cm)	2.03 ± 0.63	3.12
Fresh biomass (g)	5.43 ± 0.46	8.52
% epicarp	9.41 ± 1.19	12.59
% pulp	90.59 ± 1.18	1.31
Moisture in epicarp (%)	69.55 ± 3.21	4.61
Moisture in pulp (%)	87.00 ± 1.61	1.85
Firmness	8.32 ± 0.19	2.31
SS (°Brix)	11.25 ± 0.87	7.70
AT (g citric acid 100 mL^{-1})	2.35 ± 0.31	13.35
SS/AT	4.87 ± 0.67	13.80
pH	3.20 ± 0.15	4.62
Ascorbic acid (mg 100 mL^{-1})	143.43 ± 10.67	7.44
CO_2 (mg kg^{-1} h^{-1})	25.72 ± 1.70	6.76

The total percentage of epicarp was 9.41%, totaling 90.59% pulp yield (endocarp + mesocarp). This information is important because, in the pulping process, the epicarp is not incorporated into the pulp, as it is very hairy. Dovyalis presented a high moisture content, showing values of 69.55% moisture in the fruit peel and 87% in its pulp. Fruits generally have moisture values higher than 70%; these moisture values are related to the stability, quality, and composition of the fruit and may affect the storage, types of packaging used, and the processing of these products (Almeida et al., 2011).

Table 3 presents the chemical analyses of the dovyalis fruits. The fruits presented SS of 11.25 °Brix and AT of 2.35 g of citric acid in 100 mL^{-1}, corroborating Silva et al. (2011). The acidity found in the fruits is extremely important in industry, as it slows the manifestation of microorganisms and consequently confers a longer shelf life for the product (Negreiros, Araújo Neto, Álvares, Lima, & Oliveira, 2008). However, acidity does not provide a very sweet flavor, which does not please the consumers of the fruits *in natura*.

The SS/AT ratio indicates the degree of balance between the sugar content and the organic acids of the fruit (fruit quality/ripening) and is an important parameter in the selection of fruit. Although the SS and AT are parameters evaluated separately, both must be analyzed together because the fruit flavor is evaluated by the SS/AT ratio, evidencing the balance of acids and sugars and is an appropriate parameter for measuring the perception of taste by the consumer (Chitarra & Chitarra, 2005). The dovyalis fruits showed a low SS/AT ratio, approximately 4.87, indicating that it is a more acidic fruit and has a low ripening index. When higher values are observed, as is also the case for physalis (8.80), the dovyalis fruits are in a more advanced stage of ripening (Lima et al., 2009).

The pH value obtained for dovyalis fruits was 3.20, which is a low pH, as expected since the natural characteristic of this fruit is its acidic taste. This characteristic is desirable for industrialization of the fruit, as the optimal pH for the formation of the gel in the manufacture of jellies is from 3 to 3.20. Thus, dovyalis are suitable for processing, as they do not use acidulants in the manufacture of jellies, reducing costs at this stage.

Dovyalis fruits they had, on average, 143 mg vitamin C 100 g^{-1} of pulp, a concentration that is above of that of other fruits, making them a good source of vitamin C. Similar values were found in Roman dovyalis, according to Almeida, Jesus, and Martins (2011). The dovyalis fruits presented respiratory activity of 25.72 mg kg^{-1} h^{-1}, with this variable being an important aspect in the definition of the fruit harvest time. Besides constituting one of the ripening indices of climacteric fruits (Chitarra & Chitarra, 2005), the respiratory rate also defines the storage potential of the fruit. Therefore, dovyalis fruits present characteristics of a climacteric fruit, due to their high respiratory rate.

Table 1 shows the color, a physical characteristic of dovyalis fruits. This variable is an important parameter for fruit growers and consumers, as it indicates whether the fruit presents ideal conditions for its commercialization and consumption. However, in most cases, color does not contribute to an effective increase in the nutritional value or quality of this product (Chitarra & Chitarra, 2005). In general, consumers prefer fruits with bright color.

The variation from a green color to reddish purple, which occurs in the epicarp of dovyalis fruits, is one of the characteristics that occur during the ripening of this fruit. The change in epicarp color is a consequence of changes in the content of the total pigments, such as chlorophylls a and b and carotenoids, which are degraded and synthesized, respectively, during the ripening process (Jiménez, Mora-Newcomer, & Gutiérrez-Soto, 2014). This change in color is also used by the consumer to judge the degree of ripening and the quality of the fruits. At harvest, the epicarp of the fruit is completely reddish purple, and the harvest must be conducted every 2 to 3 days. The appearance of purple color in the endocarp can also be related to the large amounts of phenolic compounds present in the fruits.

The results obtained in the present work are satisfactory, but more comprehensive future studies should be conducted on the harvesting points for dovyalis fruits, their stages of ripening, other physicochemical characterizations, and the bioactive components and type of fruit utilization to elucidate some important post-harvest aspects of these small fruits.

Conclusion

Dovyalis fruits present high antioxidant capacity and are characterized as acidic fruits due to the high FRAP activity.

Dovyalis fruits have very attractive coloration and high acidity, which make the fruit appropriate for processing.

Flavonoids and anthocyanins are the bioactive compounds contributing most to the fruit's antioxidant activity.

High ascorbic acid content was observed in ripe dovyalis fruits.

Dovyalis fruits can be considered climacteric.

References

Abe, L. T., Lajolo, F. M., & Genovese, M. I. (2012). Potential dietary sources of ellagic acid and other antioxidants among fruits consumed in Brazil: Jabuticaba (*Myrciaria jaboticaba* [Vell.] Berg). *Journal of the Science of Food and Agriculture*, *92*(8), 1679-1687. doi: 10.1002/jsfa.5531.

Abreu, S. P. M., Peixoto, J. R., Junqueira, N. T. V., & Sousa, M. A. F. (2009). Características físicoquímicas de cinco genótipos de maracujazeiro-azedo cultivados no Distrito Federal. *Revista Brasileira de Fruticultura*, *31*(2), 487-491.

Almeida, E. J., Jesus, N., & Martins, A. B. G. (2011). Fenologia do florescimento e frutificação do Dovialis. *Científica*, *39*(1/2), 79-84.

Andreucetti, C., Ferreira, M. D., Moretti, C. L., & Honório, S. L. (2007). Qualidade pós colheita de frutos de tomate cv. Andréa tratados com etileno. *Horticultura Brasileira*, *25*(1), 122-126.

Association of Official Analytical Chemist [AOAC]. (2005). *Official Methods of Analysis of the AOAC* (18th ed.). Gaithersburg, MD: AOAC.

Benassi, M. T., & Antunes, A. J. (1988). A comparison of meta-phosphoric and oxalic acids as extract ant solutions for the determination of vitamin C in selected vegetables. *Arquivos de Biologia e Tecnologia*, *31*(4), 507-513.

Borges, G., Degeneve, A., Mullen, W., & Crozier, A. (2010). Identification of flavonoid and phenolic antioxidants in black currants, blueberries, raspberries, red currants, and cranberries. *Journal of Agricultural and Food Chemistry, 58*(7), 3901-3909. doi: 10.1021/jf902263n.

Borguini, R. G., Bastos, D. H. M., Moita Neto, J. M., Capasso, F. S., & Torres, E. A. F. S. (2013). Antioxidant potential of tomatoes cultivated in organic and conventional systems. *Brazilian Archives of Biology and Technology*, *56*(4), 521-529. doi: 10.1590/S1516-89132013000400001.

Carlsen, M. H., Halvorsen, B. L., Holte, K., Bohn, S. K., Dragland, S., Sampson, L., Jacobs, D. R., & Blomhoff, R. (2010). The total antioxidant content of more than 3100 foods, beverages, spices, herbs and supplements used worldwide. *Nutrition Journal London*, *9*(3), 1-11. doi: 10.1186/1475-2891-9-3.

Celant, V. M., Braga, G. C., Vorpagel, J. A., & Salibe, A. B. (2016). Phenolic composition and antioxidant capacity of aqueous and ethanolic extracts of blackberries. *Revista Brasileira de Fruticultura*, 38(2), 411-415. doi: 10.1590/0100-29452016411.

Chang, C. C., Yang, M. H., Wen, H. M., & Chern, J. C. (2002). Estimation of total flavonoid content in propolis by two complementary colorimetric methods. *Journal of Food and Drug Analysis, 10*(3), 178-182.

Chitarra, M. I. F., & Chitarra, A. B. (2005). *Pós-colheita de frutas e hortaliças:* fisiologia e manuseio. Lavras, MG: UFLA.

Cho, E., Seddon, J. M., Rosner, B., Willett, W. C., & Hankinson, S. E. (2004). Prospective study of intake of fruits, vegetables, vitamins, and carotenoids and risk of age-related maculopathy. *Archives of Ophthalmology, 122*(6), 883-892.

Cunha Jr., P., Jacomino, A. P., Trevisan, M. J., & Scarpare Filho, J. A. (2011). Altas concentrações de oxigênio favorecem a conservação de morango 'Oso Grande'. *Revista Brasileira de Fruticultura*, *33*(4), 1074-1083. doi: 10.1590/S0100-29452011000400005.

De Ancos, B., Sgroppo, S., Plaza, L., & Cano, M. P. (2002). Possible nutritional and health-related value promotion in orange juice preserved by high-pressure treatment. *Journal of the Science of Food and Agriculture*, *82*(8), 790-796.

Ellong, E. N., Billard, C., Adenet, S., & Rochefort, K. (2015). Polyphenols, carotenoids, vitamin C content in tropical fruits and vegetables and impact of processing methods. *Food and Nutrition Sciences*, *6*(3), 299-313. doi: 10.4236/fns.2015.63030.

Ferreira, D. F. (2011). Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia, 35*(6), 1039-1042. doi: 10.1590/S1413-70542011000600001.

George, S., Brat, P., Alter, P., & Amiot, M.J. (2005). Rapid determination of polyphenols and vitamin C in plant-derived products. *Journal of Agricultural and Food Chemistry, 53*(5), 1370-1373.

Horst, M. A., & Lajolo, F. M. (2011). *Biodisponibilidade de compostos bioativos de alimentos*. Retrieved on Dec. 12, 2017 from www.fcf.usp.br

Instituto Adolfo Lutz [IAL]. (2008). *Métodos físico-químicos para análises de alimentos* (4a ed.). São Paulo, SP: Instituto Aldolfo Lutz.

Jacques, A. C., Pertuzatti, P. B., Barcia, M. T., & Zambiazi, R. C. (2009). Compostos bioativos em pequenas frutas cultivadas na região sul do Estado do Rio Grande do Sul. *Brazilian Journal of Food Technology*, *12*(2), 123-127.

Jacques, A. C., & Zambiazi. (2011). Fitoquímicos em amora-preta (*Rubus* spp.). *Semina: Ciências Agrárias*, *32*(1), 245-260.

Jiménez, V. M., Mora-Newcomer, E., & Gutiérrez-Soto, M. V. (2014). Biology of the papaya plant. In R. Ming, & P. H. Moore (Ed.), *Genetics and genomics of papaya, plant genetics and genomics: crops and models 10* (p. 17-33). New York, US: Springer Science-Business Media.

Lee, J., Durst, R. W., & Wrolstad, R. E. (2005). Determination of total monomeric anthocyanin pigment content of fruit juices, beverages, natural colorants, and wines by the pH differential method: Collaborative Study. *Journal of AOAC International*, *88*(5), 1269-1278.

Lima, C. S. M., Severo, J., Manica-Bento, R., Silva, J. A., Rufato, L., & Rufato, A. R. (2009). Característica físico-químicas de physalis em diferentes colorações do cálice e sistemas de condução. *Revista Brasileira de Fruticultura*, *31*(4), 1060-1068.

Maia, G. A., Sousa, P. H. M., Santos, G. M., Silva, D. S., Fernandes, A. G., & Prado, G. M. (2007). Efeito do processamento sobre componentes do suco de acerola. *Food Science and Technology*, *27*(1), 130-134.

Munsell, A. H. (1976). *Munsell color charts for plants tissues.* Maryland, US: Macbeth Division of kollmorgen instruments corporation.

Nascimento, R. S. M., Cardoso, J. A., & Cocozza, F. D. M. (2014). Caracterização física e físico-química de frutos de mangabeira (*Hancornia speciosa* Gomes) no oeste da Bahia. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *18*(8), 856-860. doi: 10.1590/1807-1929/agriambi.v18n08p856-860

Negreiros, J. R. S., Araújo Neto, S. E., Álvares, V. S., Lima, V. A., & Oliveira, T. K. (2008). Caracterização de frutos de progênies de meios irmãos de maracujazeiro-amarelo em Rio Branco - Acre. *Revista Brasileira de Fruticultura, 30*(2), 431-437.

Pereira, I. S., Antunes, L. E. C., Silveira, C. A. P., Messias, R. S., Gardin, J. P. P., Schneider, F. C., & Pillon, C. N. (2009). *Caracterização agronômica da amoreira-preta cultivada no Sul do estado do Paraná* (Embrapa Clima Temperado. Documentos, 271). Pelotas, RS: Embrapa Clima Temperado..

Pérez-Jiménez, J., Arranz, S., Tabernero, M., Díaz-Rubio, M. E., Serrano, J., Goni, I., & Saura-Calixto, F. (2008). Updated methodology to determine antioxidant capacity in plant foods, oils and beverages: extraction,

measurement and expression of results. *Food Research International*, *41*(3), 274-285.

Rocha, M. S., Figueiredo, R. W., Araujo, M. A. M., & Moreira-Araujo, R. S. R. (2013). Caracterização físico-química e atividade antioxidante (in vitro) de frutos do cerrado Piauiense. *Revista Brasileira de Fruticultura, 35*(4), 933-941. doi: 10.1590/S0100-29452013000400003

Rufino, M. S. M., Alves, R. E., Brito, E. S., Morais, S. M., Sampaio, C. G., Pereéz-Jiménez, J., & Saura-Calixto, F. D. (2007). *Metodologia Científica: determinação da atividade antioxidante total em frutas pela captura do radical livre DPPH* (Comunicado Técnico *on line*, 127). Fortaleza, CE: Embrapa.

Saura-Calixto, F., & Goñi, I. (2006). Antioxidant capacity of the Spanish Mediterranean diet. *Food Chemistry, Barking, 94*(1), 442-447.

Silva, J. A. A., Grizotto, R. K., Miguel, F. B., & Bárbaro, I. M. (2011). Caracterização físico-química de frutos de clones de dovyalis (*Dovyalis abyssinica* Warb). *Revista Brasileira de Fruticultura, 33*(esp.), 466-472. doi: 10.1590/S0100-29452011000500062.

Souza, V. R., Pereira, P. A. P., Silva, T. L. T., Lima, L. C. O., Pio, R., & Queiroz, F. (2014). Determination of the bioactive compounds, antioxidant activity and chemical composition of Brazilian blackberry, red raspberry, strawberry, blueberry and sweet cherry fruits. *Food Chemistry*, *156(1)*, 362-368. doi: 10.1016/j.foodchem.2014.01.125.

Sucupira, N. R., Silva, A. B., Pereira, G., & Costa, J. N. (2012). Métodos para determinação da atividade antioxidante de frutos. *UNOPAR Científica: Ciências Biológicas e Saúde*, *14*(4), 263-269.

Zhu, S., & Zhou, J. (2007). Effect of nitric oxide on ethylene production in strawberry fruit during storage. *Food Chemistry*, *100*(2), 1517-1522.

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