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Bioactive and yield potential of jelly palms (*Butia odorata* Barb. Rodr.)

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ABSTRACT

In this descriptive study, *Butia odorata* genotypes were evaluated for yield, fruit number, pulp yield, bioactive content (including phenolic compounds, carotenoid, anthocyanin, L-ascorbic acid, and fibre content), antioxidant potential, and phenotypic characteristics. Genotype 117 was the highest yielding, with an estimated fruit yield of 22,000 kg ha^{-1} and pulp yield of 12,000 kg ha^{-1}. On the other hand, the lowest yielding genotype, accession 49, showed an estimated fruit yield of 8400 kg ha^{-1}. Jelly palm fruit were generally rich in phenolic content (280.50–398.50 mg 100^{-1} g), carotenoid content (2.80–4.08 mg 100 g^{-1}), and L-ascorbic acid content (34.63–63.84 mg 100 g^{-1}). While the highest yielding genotype was not the richest in bioactive content, the lowest yielding genotype showed the highest L-ascorbic acid content. Although fruit yield and phytochemical composition are desirable attributes in jelly palm fruit, none of the genotypes evaluated showed high levels of both. Therefore, fruit yield and bioactive phytochemical content appear to be inversely proportional.

1. Introduction

Brazil is known to possess approximately 30% of the tropical forests on the planet, harbouring a huge base of plant genetic diversity distributed in the following biomes: Amazônia, Cerrado, Caatinga, and part of Mata Atlântica. In addition, there also exists significant species richness in subtropical and temperate climates within part of the Mata Atlântica and the Pampa biome. Despite this biodiversity, most species remain undomesticated, and limited scientific research has been conducted to describe such diversity. It is estimated that only 5% of known species have been investigated for agronomic, phytochemical, and biological potential (Calixto, 2005; Medina et al., 2011). Therefore, characterisation of native species is an important step in promoting new and underutilised species (Nascimento, Moura, Vasconcelos, Maciel, & Albuquerque, 2011). Successful examples where scientific investigation contributed to the preservation and promotion of relevant genetic resources include açaí [*Euterpe precatoria* Mart.] (Yuyama et al., 2011), camu-camu [*Myrciaria dubia* Kunth] (Hernández, Carrillo, Barrera, & Fernández-Trujillo, 2011), acerola [*Malpighia glabra* L.] (Yamashita, Benassi, Tonzar, Moriya, & Fernández, 2003), cupuaçu [*Theobroma grandiflorum* Willd. ex Spreng.] (Souza, Vieira, Silva, & Lima, 2011), and araçá [*Psidium* sp.] (Medina et al., 2011).

Arecaceae is a botanical family with vast genetic diversity found in southern Brazil and Uruguay containing six genera partially described: *Bactris*, *Butia*, *Euterpe*, *Geonoma*, *Syagrus*, and *Trithrinax*. *Butia* species are palms with a single stem that may reach 10 m tall, with fruit ovoid to depressed-globose, ranging from yellow to orange to red in colour, with a sweet, acidic, meaty mesocarp. *Butia* spp. fruits are highly appreciated for fresh consumption or processed into juice, liquor, pulp, or frozen (Schwartz, Fachinello, Barbieri, & Silva, 2010). Leaves posses a pseudopetiole with flat and rigid fibres forming spikes along the border (Lorenzi, Noblick, Kahn, & Ferreira, 2010). Plants occur naturally in aggregate populations, at times extensive and in large number called "butiazais". Deforestation for farming and the use of *Butia* trees for landscaping has contributed to a population reduction (Nunes, Fachinello, Radmann, Bianchi, & Schwartz, 2010). As part of an effort to protect the species, there is a need to characterise the available genetic material, develop propagation methods, and study production practices, as it usually takes ten years from planting until the first fruit harvest (Broschat, 1998). These studies are important to the domestication of wild species, which are generally richer in minerals, fibre, and antioxidant molecules, than domesticated species (Kinupp & Barros, 2008). Fruit physicochemical characteristics influence their conservation requirements as well as their potential application. Physicochemical characterisation of jelly palm or butia fruit have been performed in order to explore their potential use, improve conservation, and aid in

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species identification (Dal Magro, Coelho, Haida, Berté, & Moraes, 2006; Nunes et al., 2010; Pedron, Menezes, & Menezes, 2004).

In addition to preserving centuries old populations existing in southern South America, there is a need to establish new orchards for species maintenance. Within this context, the objective of this study was to characterise *Butia odorata* fruit from the Universidade Federal de Pelotas germplasm collection in order to identify genotypes with high qualitative and quantitative potential.

2. Material and methods

2.1. Experimental site and plant material

Jelly palm (*B. odorata* Barb. Rodr.) fruit were harvested from a research orchard (germplasm collection from Centro Agropecuário da Palma, UFPel, Pelotas, RS, Brazil; latitude 31° 52′ 00″ S latitude, 52° 21′ 24″ W Greenwich longitude and altitude of 13,24 m) between February and April 2013. The five genotypes studied (accession numbers 49, 76, 88, 115, and 117) were grown from seeds harvested from a non-domesticated population in Santa Vitória do Palmar, RS, Brazil. Each genotype was a 23-year-old plant with a stipe of 1.3 m tall and an average of 20 leaves. Trees were spaced with 6 m between rows and 4 m between plants. From May to August, both bunches which had held fruit and senescing leaves were removed. Fruit was harvested when ripe, washed, and frozen in liquid nitrogen and stored at −76 °C until further analyses. All analyses were performed in triplicate.

2.2. Morphological characteristics

For evaluation of morphological characteristics, three bunches per plant were selected and 30 fruit per bunch were utilised, totaling 90 fruit per plant. Each group of 30 fruit were pooled to compose a replicate. Fruit were manually depulped and fruit juice was separated from the fibre using a juicer (Wallita). Pulp yield was calculated as mL of fruit juice 100 g^{-1} of fruit.

2.3. Soluble solids (SS), pH and total acidity (TA)

Soluble solids content was determined by refractometry, and results were expressed as °Brix. Total acidity (TA) and pH were measured directly in extracted fruit juice. TA was determined by titration and results were expressed as mg of citric acid 100 g^{-1} fw. These analyses were performed according to AOAC (2005).

2.4. Carotenoid content

Frozen fruit flesh, equivalent to 30 g of fresh fruit, was ground under liquid nitrogen with a mortar and pestle, suspended in 60 mL of acetone (80% v/v), stirred for 15 min, and filtered. The extraction process was repeated three times. The filtrate was then centrifuged at 10,000*g* for 15 min and the supernatant was concentrated and brought to 40 mL with acetone. Absorbance was measured at 646, 663, and 470 nm in an UV/Vis spectrophotometer. Total carotenoid content was determined using the equations described by Lichtenthaler and Wellburn (1983) and expressed as mg β-carotene equivalents 100 g^{-1} fw.

Individual carotenoids were quantified by HPLC (Shimadzu) using an Ultracarb 30-ODS (5 μm × 4.6 mm × 150 mm) column, and UV detector set at 450 nm (Tiecher, de Paula, Chaves, & Rombaldi, 2013). The separation was carried out using a gradient elution including methanol (A), acetonitrile (B), and ethyl acetate (C). An elution gradient started with 30% A and 70% B for 10 min, followed by 10% A/80% B/10% C for 10 min; and 5% A/80% B/15% C for 15 min, and back to the starting conditions for 2.5 min. Flow rate was set at 1 mL min^{-1}. Individual carotenoid content was calculated based on calibration curves using the external standards were purchased from Sigma–Aldrich (Saint-Louis, MO, USA): β-carotene, zeaxanthin, β-criptoxanthin, and lycopene and expressed as mg 100 g^{-1} fw.

2.5. Anthocyanin content

Anthocyanin content was determined by spectrophotometry (Lees & Francis, 1972). Five grams of fruit flesh were ground to powder in liquid nitrogen, suspended in 50 mL of acidic ethanol (0.01% HCl), and allowed to rest for two hours in the dark. The mixture was centrifuged at 10,000*g* for 20 min at 4 °C. The precipitate was washed three times using 5 mL of cold acidified methanol and centrifuged again. The supernatant was filtered through a Whatman No. 1 filter by vacuum suction and concentrated using a rotary evaporator at 30 °C. The anthocyanin rich residue was diluted to 10 mL with acidified deionised water (0.01% v/v HCl), and the aqueous extract was then injected into a C18-E column (Strata, 550 mg/6 mL) preconditioned with two column volumes of methanol and three column volumes of acidified deionised water (0.01% v/v HCl). The column was washed with two column volumes of acidified water before the ethyl acetate final washing. Anthocyanin elution was carried out with acidified methanol (0.01% v/v HCl). The eluate was concentrated to 10 mL using a rotary evaporator. The anthocyanin fraction was measured at 530 nm with a spectrophotometer, and total anthocyanin content was expressed as mg of cyanidin-3-glucoside equivalents 100 g^{-1} fw.

Individual anthocyanins were quantified according to Zhang, Kou, Fugal, and McLaughlin (2004). An aliquot of 10 μL was injected into the HPLC (Shimadzu) system with UV–Vis detector at 520 nm. The mobile phase consisted of a gradient elution with aqueous acetic acid (98:2% v/v) (A), methanol (B), acetonitrile (C) at a flow rate of 0.8 mL min^{-1} starting at 100% A, changing to 90% A and 10% B after 10 min; and to 80% A, 10% B and 10% C after 5 min and held for 10 min; and to 70% A and 30% B after 5 min and held for 5 min; finally returning to the initial conditions after 5 min for a total run time of 40 min. Individual anthocyanin content (mg 100 g^{-1} fw) was calculated based on calibration curves using the external standards purchased from Sigma–Aldrich: kuromanin (cyanidin-3-glucoside chloride) and keracyanin (cyanidin-3-*O*-rutinoside chloride).

2.6. Phenolic compounds content

The total phenolic compounds content was determined using the Folin–Ciocalteau reagent according to the protocol optimised by Severo, Tiecher, Chaves, Silva, and Rombaldi (2011) for the analyses of these compounds in strawberry. One gram of fruit flesh powder ground in liquid nitrogen was suspended in 60 mL of deionised water and 5 mL of Folin–Ciocalteau reagent. Absorbance was measured at 725 nm and results were expressed as mg of gallic acid equivalents 100 g^{-1} fresh weight. Determination of individual phenolic compounds by RP-HPLC followed the methodology developed by Hakkinen, Kärenlampi, Heinonen, Mykkänen, and Torronen (1998) and adapted by Severo et al. (2011) for analyses of strawberry fruit. Quantification was based on external standard calibration curves for gallic acid, ρ-hydroxybenzoic acid, ρ-coumaric acid, ferulic acid, caffeic acid, (+)-catechin, (−)-epicatechin, quercetin, and kaempferol (Sigma–Aldrich) and results were expressed as mg 100 g^{-1} fw.

2.7. Ascorbic acid content

Ascorbic acid (AA) extracted with metaphosphoric acid (1% w/v) was determined using an RP-HPLC method developed by Vinci,

Botre, Mele, and Ruggieri (1995) and further adapted by Severo et al. (2011). Quantification was based on an external standard calibration curve using L-(+)-ascorbic acid (Sigma–Aldrich). Results were expressed as mg of ascorbic acid 100 g^{-1} fw.

2.8. Antioxidant potential

The antioxidant potential of butia fruit was determined using the ABTS assay developed by Re et al. (1999) and adapted by Severo et al. (2011). Results were expressed as mg trolox equivalent antioxidant capacity (TEAC) 100 g^{-1} fw. Quantification was based on an external standard calibration curve using trolox (Sigma–Aldrich).

2.9. Dietary fibre content

Total and insoluble dietary fibre analyses were carried out according to AOAC (2005) protocol by a non-enzymatic gravimetric method. The results were expressed in g 100 g^{-1} of total soluble and insoluble dietary fibre. Soluble dietary fibre content was calculated as the difference between total and insoluble dietary fibre.

2.10. Statistical analysis

Data were analysed for normality using Shapiro–Wilk's test, homoscedasticity with Hartley's test, and residual independence was verified graphically. Subsequently, data was subjected to analysis of variance ($p \leqslant 0.05$), and means were compared by Tukey's test ($p \leqslant 0.05$) using SAS 9.2 (Cary, NC). The experimental design was completely randomised with three replicates.

3. Results and discussion

Since the *Butia* plant is an endemic native species to southern Brazil and Uruguay and highly adapted to ecosystems characterised by marked abiotic stresses, it is expected to possess significant morphological, phonological, and phytochemical variability. As expected, variation in yield and bioactive compound content was observed here (Tables 1–6). During the field evaluation of the plants, no symptoms of pathogen attack were observed indicating the hardiness of this crop.

Average fruit yield per plant ranged from 52.89 kg (genotype 117) to 20.19 kg (genotype 49), with bunch weight varying from 13.72 kg (genotype 117) to 3.97 kg (genotype 49), and fruit number ranging from 699 (genotype 117) to 403 (genotype 88). The genotypes with the highest juice yields were 117 and 88, while accession 49 had the lowest juice yield. Assuming an orchard with 416 plants per ha^{-1}, the estimated fruit yield and pulp yield per hectare for genotype 117 would be 22,002 kg ha^{-1} and 12,143 kg ha^{-1}, respectively. In addition, it was observed that the highest yielding genotypes were also those with the highest pulp yield. Given the above plant density, the lowest yielding genotype (accession 49) would yield 8400 kg fruit ha^{-1}, and 3271 kg pulp ha^{-1}. Despite not having undergone breeding or cycles of selection, these accessions possess high fruit and pulp yield potential. Moreover, such high yields were realised with no inputs (fertilizer, pesticides, or irrigation). When compared, for example, to peaches grown in the same ecosystem which produce 14,060 kg fruit ha^{-1} and demand eight spraying treatments in an integrated production strategy (Fachinello et al., 2003), *Butia* is a promising low input high yielding fruit crop.

In general, jelly palm or butia fruits are described as juicy, sweet, acidic, and with a unique flavour (Ferrão et al., 2013). Fruit of the genotypes studied here were characterised as having a globose depressed shape, and being yellow (genotype 117), orange (genotypes 49, 76 and 88), or red (genotype 115) in colour.

Regarding their general composition (Table 1), the fruit were acidic (pH varying from 2.96 to 3.05 and acidity 1.12 to 1.30% citric acid), with elevated soluble solids content (from 13.15 to 14.56 °Brix) and high specialised metabolites content (Table 2).

Butia fruit are characterised as being rich in phenolic content and carotenoid content as well as ascorbic acid content. Butia phenolic content ranged from 265 to 402 of gallic acid equivalents,

Table 1
Yield, weight (bunch and fruit) and number of fruits per bunch, juice yield, pH and soluble solids (SS) content of jelly palm (*Butia odorata*) genotypes.

Genotype	Yield (kg $plant^{-1}$)	Potential yield (kg ha^{-1})	Bunch weight (kg^{-1})	Fruit weight (g)	Fruits (per bunch)	Juice yield (mL 100 g^{-1})	pH	SS (°Brix)
	20.19	8400	3.97 ± 0.39^{b}	8.77 ± 0.69^{c}	466 ± 73.13^{a}	38.95 ± 6.35^{c}	2.96 ± 0.03^{a}	13.15 ± 0.35^{a}
	37.78	15,720	6.53 ± 1.32^{b}	14.66 ± 1.47^{bc}	475 ± 106.73^{a}	46.57 ± 13.20^{bc}	2.99 ± 0.03^{a}	13.73 ± 1.21^{a}
	40.49	16,840	8.55 ± 1.57^{ab}	23.06 ± 3.26^{a}	403 ± 61.93^{a}	54.64 ± 2.59^{ab}	2.99 ± 0.06^{a}	13.73 ± 1.08^{a}
	34.37	14,300	5.20 ± 0.21^{b}	9.95 ± 0.29^{c}	543 ± 35.10^{a}	46.58 ± 2.23^{c}	3.05 ± 0.03^{a}	14.56 ± 0.86^{a}
	52.89	22,000	13.72 ± 1.73^{a}	18.51 ± 4.16^{ab}	699 ± 59.50^{a}	55.19 ± 4.34^{a}	2.98 ± 0.03^{a}	13.41 ± 2.64^{a}

Values expressed as means ± standard deviation. Means followed by the same letter in a column are not significantly different by Tukey's test ($p \leqslant 0.05$). Potential yield was estimated assuming an average of 416 plants per ha^{-1}.

Table 2
Total acidity, total phenolic compound content, total carotenoid content, anthocyanin, L-ascorbic acid and antioxidant capacity of jelly palm (*Butia odorata*).

Genotype	Total acidity (mg 100 g^{-1})	Phenolic (mg 100 g^{-1})	Carotenoid (mg 100 g^{-1})	Anthocyanin (mg 100 g^{-1})	L-ascorbic acid (mg 100 g^{-1})	Antioxidant capacity (mg 100 g^{-1})
49	1.12 ± 0.10^{a}	380.00 ± 5.00^{a}	3.94 ± 0.52^{a}	1.11 ± 0.14^{b}	63.84 ± 4.16^{a}	440 ± 5.00^{b}
76	1.30 ± 0.05^{a}	293.00 ± 3.00^{b}	2.80 ± 0.98^{b}	1.46 ± 0.22^{b}	37.31 ± 1.69^{b}	310 ± 1.00^{c}
88	1.3 ± 0.01^{a}	398.50 ± 3.50^{a}	4.08 ± 1.17^{a}	1.05 ± 0.08^{b}	54.83 ± 1.17^{a}	433 ± 8.00^{b}
115	1.18 ± 0.05^{a}	373.00 ± 5.00^{a}	3.03 ± 0.66^{b}	25.13 ± 1.87^{a}	35.98 ± 0.97^{b}	540 ± 28.00^{a}
117	1.26 ± 0.01^{a}	280.50 ± 15.50^{b}	2.88 ± 0.84^{b}	1.07 ± 0.04^{b}	34.63 ± 0.63^{b}	305 ± 7.00^{c}

Values expressed as the mean ± standard deviation of the mean. Means followed by the same letter in a column are not significantly different by Tukey's test ($p \leqslant 0.05$).

Table 3
Anthocyanin and carotenoid content of jelly palm (*Butia odorata*).

Genotype	Anthocyanin (mg 100 g^{-1})		Carotenoid (mg 100 g^{-1})			
	Keracyanin	Kuromanin	β-Carotene	β-Criptoxanthin	Lycopene	Zeaxanthin
49	0.91 ± 0.11^{b}	0.15 ± 0.03^{b}	1.11 ± 0.09^{a}	2.67 ± 0.13^{a}	0.01 ± 0.01^{b}	0.27 ± 0.03^{a}
76	0.92 ± 0.04^{b}	0.20 ± 0.01^{b}	0.53 ± 0.07^{c}	2.17 ± 0.03^{b}	0.01 ± 0.01^{b}	0.04 ± 0.02^{b}
88	0.76 ± 0.01^{b}	0.17 ± 0.06^{b}	1.06 ± 0.14^{ab}	2.59 ± 0.10^{b}	0.10 ± 0.01^{a}	0.10 ± 0.02^{ab}
115	19.9 ± 1.21^{a}	5.02 ± 0.67^{a}	0.82 ± 0.08^{ab}c	2.07 ± 0.03^{b}	0.03 ± 0.01^{b}	0.17 ± 0.07^{ab}
117	1.02 ± 0.06^{b}	0.06 ± 0.06^{b}	0.58 ± 0.02^{bc}	2.23 ± 0.13^{b}	0.01 ± 0.01^{b}	0.02 ± 0.01^{b}

Values expressed as means ± standard deviation. Means followed by the same letter in a column are not significantly different by Tukey's test ($p \leqslant 0.05$).

Table 4
Phenolic acids (mg 100 g^{-1}) of jelly palm (*Butia odorata*).

Genotypes	Gallic	Hydroxybenzoic	Coumaric	Ferulic	Caffeic
49	234.29 ± 8.32^{a}	121.09 ± 7.38^{ab}	0.99 ± 0.04^{b}	4.12 ± 0.08^{a}	1.04 ± 0.24^{d}
76	117.04 ± 0.04^{c}	123.53 ± 0.85^{ab}	1.05 ± 0.13^{b}	1.06 ± 0.13^{c}	0.46 ± 0.01^{e}
88	230.17 ± 4.30^{a}	106.52 ± 4.82^{b}	1.09 ± 0.17^{b}	0.88 ± 0.15^{c}	3.04 ± 0.13^{b}
115	210.07 ± 3.05^{b}	150.14 ± 12.69^{a}	2.01 ± 0.04^{a}	1.08 ± 0.33^{c}	4.02 ± 0.16^{a}
117	117.10 ± 1.31^{c}	115.69 ± 2.04^{b}	1.07 ± 0.06^{b}	2.08 ± 0.08^{b}	2.13 ± 0.01^{c}

Values expressed as means ± standard deviation. Means followed by the same letter in a column are not significantly different by Tukey's test ($p \leqslant 0.05$).

Table 5
Flavonoid content (mg 100 g^{-1}) of jelly palm (*Butia odorata*).

Genotypes	(+)-Catechin	(−)-Epicatechin	Quercetin	Kaempferol
49	1.08 ± 0.06^{b}	46.56 ± 0.81^{b}	4.09 ± 0.17^{a}	4.20 ± 0.04^{a}
76	2.16 ± 0.27^{a}	38.18 ± 1.46^{c}	0.86 ± 0.22^{c}	1.04 ± 0.24^{c}
88	0.84 ± 0.12^{b}	47.00 ± 1.24^{b}	1.05 ± 0.11^{c}	1.58 ± 0.08^{b}
115	2.18 ± 0.07^{a}	52.14 ± 1.39^{a}	2.06 ± 0.11^{b}	0.83 ± 0.11^{c}
117	2.11 ± 0.06^{a}	43.30 ± 0.24^{b}	2.19 ± 0.05^{b}	1.06 ± 0.11^{bc}

Values expressed as means ± standard deviation. Means followed by the same letter in a column are not significantly different by Tukey's test ($p \leqslant 0.05$).

Table 6
Total, insoluble and soluble dietary fibre of jelly palm (*Butia odorata*).

Genotype	Total dietary fibre (g 100 g^{-1} fw)	Insoluble dietary fibre (g 100 g^{-1} fw)	Soluble dietary fibre (g 100 g^{-1} fw)
49	2.69 ± 0.06^{a}	1.69 ± 0.03^{b}	0.99 ± 0.04^{a}
76	1.38 ± 0.04^{b}	0.62 ± 0.03^{c}	0.76 ± 0.01^{bc}
88	1.05 ± 0.03^{b}	0.80 ± 0.03^{c}	0.25 ± 0.00^{d}
115	3.00 ± 0.10^{a}	2.35 ± 0.07^{a}	0.65 ± 0.03^{c}
117	2.77 ± 0.33^{a}	1.95 ± 0.36^{ab}	0.82 ± 0.09^{b}

Values are expressed as means ± standard deviation. Means followed by the same letter in a column are not significantly different by Tukey's test ($p \leqslant 0.05$).

GAE, 100 g^{-1}, and is high in relation to other fruit and vegetables widely consumed such as carrots, peas, tomatoes, and onions that possess 60 mg, 160 mg, 200 mg, and 250 mg GAE 100 g^{-1}, respectively (Kähkönen et al., 1999); and fruit such as raspberry and strawberry whose phenolic content averages 30 mg and 80 mg GAE 100 g^{-1} (Agar, Streif, & Bangerth, 1997).

Total carotenoid content of butia fruit ranged from 2.80 to 4.08 mg 100 g^{-1} and was similar to carotenoid content in blackberry cultivars Tupy and Xavante, blueberry cultivars Powder Blue and Delite, and loquat (*Eriobotrya japonica*) which had 0.91, 0.60, 0.14, 1.08, and 2.40 mg of β-carotene 100 g^{-1}, respectively (Jacques, Pertuzatti, Barcia, & Zambiazi, 2009). Carotenoid variation within species and genotypes depend on many factors including genetics, fruit ripening stage, soil type, weather conditions, and light exposure (Bagetti et al., 2011; Medina et al., 2011; Rodriguez-Amaya, 2001).

Genotype 115 had the highest total anthocyanin content (25 mg 100 g^{-1} fw), which is comparable to that of pitanga (*Eugenia uniflora*), another Brazilian native fruit tree (Bagetti et al., 2011).

L-ascorbic acid content of jelly palm varied from 34.63 to 63.84 mg 100 g^{-1}. Similarly, in *Butia capitata*, L-ascorbic acid varied from 38 to 73 mg 100 g^{-1} (Faria, Almeida, Silva, Vieira, & Agostini-Costa, 2008). Vitamin C content of buriti fruit (*Mauritia flexuosa* L.) and tucumã fruit (*Bactris setosa* Mart.), two palm trees native to Brazil, was on average 23.4 and 28 mg 100 g^{-1}, respectively (Lorenzi, Bacher, Lacerda, & Sartori, 2006). When comparing the vitamin C content of different fruit juices, butia with 63 mg 100 g^{-1} is superior to orange (50–53 mg 100 g^{-1}), uvaia (*Eugenia* sp.) (48 mg 100 g^{-1}), araçá (*Psidium cattleianum*) (39 mg 100 g^{-1}) and passion fruit (22 mg 100 g^{-1}), but less than acerola (*Malpighia* sp.) with 125.4 mg 100 g^{-1} (Quináia & Ferreira, 2007).

Genotype 115 had the highest measured antioxidant potential, and was as high as that found in other fruit such as guava (176 mg TEAC 100 mL^{-1}), pomegranate (156.37 mg TEAC 100 mL^{-1}),

passion fruit (95.17 mg TEAC 100 mL^{-1}), mango (65.24 mg TEAC 100 mL^{-1}), and apple (55.06 mg TEAC 100 mL^{-1}) (Ali, Nayan, Chanu, Ralte, & Devi, 2011).

Two anthocyanins identified in butia were keracyanin and kuromanin (Table 3). Keracyanin accounted for 80% of total anthocyanins found in accession 115. Anthocyanins are water-soluble compounds capable of acting as strong antioxidants. These molecules have been shown to have antioxidant potential comparable to synthetic antioxidants such as tert-butylhydroquinone, butylated hydroxytoluene, and butylated hydroxyanisole (Galvano et al., 2004).

β-Criptoxanthin was the predominant carotenoid followed by β-carotene, which combined made up 96% of total carotenoid content, while zeaxanthin and lycopene were minor components (Table 3).

Gallic acid was the major phenolic compound, followed by hydroxybenzoic acid. These results are similar to those of a previous study, which found 328.6 mg GAE 100^{-1} for this same species in this region (Jacques et al., 2009). Hydroxybenzoic acid usually found in citrus, grapes, and strawberry was also found in significant amounts in *Butia* (Silva, Costa, Santana, & Koblitz, 2010). Other minor phenolic compounds present were coumaric, ferulic, and caffeic acids, and the flavonoids (−)-epicatechin, quercetin, and kaempferol (Tables 4 and 5).

Butia fruit is rich in dietary fibre. This attribute has been used as a morphological marker for germplasm characterisation (Mistura, 2013). Genotypes 115, 117, and 49 showed the highest total dietary fibre content (3.0–2.7 g 100 g^{-1} fw). Genotype 115 had the highest insoluble dietary fibre content, while accession 49 had the highest soluble fibre content. *B. odorata* was found to contain 4.89 g 100 g^{-1} fw fibre (Pereira et al., 2013), and *B. capitata* had 6.3 g 100 g^{-1} fw fibre (Faria et al., 2008). Total dietary fibre in *Butia* is similar to that found in apple (2 g 100 g^{-1} fw), cupuaçu (3.1 g 100 g^{-1} fw), and Tommy Atkins mango (2.1 g 100 g^{-1} fw) (Elleuch et al., 2011).

Genotype 117 with the highest fruit and juice yield, was not the richest in phytochemical content. The highest L-ascorbic acid content was observed in genotypes 49 and 88. Genotype 115, with the highest anthocyanin content and matching antioxidant potential also had a limited yield. Among the genotypes evaluated, those with the highest accumulation of carotenoids, phenolic compounds, and L-ascorbic acid were accessions 49 and 88, while accession 115 had the highest anthocyanin content and highest antioxidant capacity.

4. Conclusion

Butia is a cross-pollinated species, and therefore a high degree of genetic variation is expected for morphological, phenological, and physicochemical characteristics. Genotype 117 with the highest fruit and pulp yield did not have the highest the phytochemical content. The highest L-ascorbic acid content was found in genotype 49, which had the lowest fruit and pulp yield. Genotype 115 had the highest anthocyanin content and a high antioxidant potential, but limited fruit yield. Diversity is essential for breeding programs and may allow for wider selection options resulting in improved germplasm. Exploring the existing potential of native populations of *Butia* will lead to the preservation of the species and the development of improved cultivars for agronomic use.

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