JOURNAL OF FUNCTIONAL FOODS 5 (2013) 539–549

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Bioactive compounds and health benefits of exotic tropical red–black berries

André Gustavo Vasconcelos Costa[a,*], *Diego F. Garcia-Diaz*[b], *Paula Jimenez*[b], *Pollyanna Ibrahim Silva*[c]

[a]*Department of Pharmacy and Nutrition, Center for Agrarian Sciences, Federal University of Espírito Santo, Alegre, Brazil*
[b]*Department of Nutrition, School of Medicine, University of Chile, Santiago, Chile*
[c]*Department of Food Engineering, Center for Agrarian Sciences, Federal University of Espírito Santo, Alegre, Brazil*

ARTICLE INFO

Article history:
Received 18 October 2012
Received in revised form
22 January 2013
Accepted 22 January 2013
Available online 19 February 2013

Keywords:
Bioactive compound
Tropical fruit
Euterpe
Eugenia
Myrciaria
Syzygium

ABSTRACT

Tropical countries produce a large amount of native and exotic fruit species which are potentially interested in the food industry. The nutritional and therapeutic values in this fruits are mainly due to the presence of bioactive compounds, especially polyphenols. The anthocyanins belong to the flavonoid family and represent a group of pigments responsible for most of the colors in fruits, leaves, flowers, stems and roots of plants. Several investigations have focused on the health benefits of consumption of red–black fruit, claiming these as natural sources of bioactive compounds with highly promising antioxidant and anti-inflammatory characteristics. Furthermore, the consumption of red–black berries brings a positive impact on several chronic conditions, such as obesity, diabetes, cancer, cardiovascular and neurodegenerative diseases. This article summarizes the foremost bioactive compounds and the health properties of exotic tropical red–black berries, specifically *Euterpe oleracea*, *Eugenia uniflora*, *Myrciaria cauliflora*, *Myrciaria dubia*, *Syzygium cumini*.

Contents

* *Corresponding author*. Address: Universidade Federal do Espírito Santo, Centro de Ciências Agrárias, Departamento de Farmácia e Nutrição, Alto Universitário, s/n, Guararema, 29500-000 Alegre, ES, Brazil. Tel./fax: +55 28 3552 8661.
E-mail address: agvcosta@yahoo.com.br (A.G.V. Costa).

Abbreviations: ABTS, 2,2-azinobis (3-ethylbenzothiazoline-6-sulfonic) acid radical; DPPH, 2,2-diphenyl-1-picrylhydrazyl; DW, dry weight; FAE, ferulic acid equivalents; FRAP, ferric reducing antioxidant power; FW, fresh weight; GAE, gallic acid equivalents; IL, interleukine; LDL, low density lipoprotein; LPS, lipopolysaccharide; NF-κB, nuclear factor κB; ORAC, oxygen radical absorbance capacity; ROS, reactive oxygen species

1756-4646/$ - see front matter
http://dx.doi.org/10.1016/j.jff.2013.01.029

1. Introduction

A diet rich in fruits and vegetables has a positive impact on several chronic conditions, such as obesity, diabetes, cancer, cardiovascular and neurodegenerative diseases (Leite et al., 2011). The fruits are consumed as sources of water and essential nutrients such as vitamins, minerals and fiber. However, in some cases fruits are consumed due to their antioxidant properties. The health properties and the chemical composition of fruits from Europe and North America have been described in the scientific literature, whereas those native from South America have been less studied (Clerici & Carvalho-Silva, 2011; Schreckinger, Lotton, Lila, & de Mejia, 2010).

Tropical countries produce a large amount of native and exotic fruit species which are potentially interesting for the food industry. Exotic fruits, consumed regionally are gaining popularity in the marketplace due to their nutritional and therapeutic value, but also because of their pleasant flavors and variety of color (Clerici & Carvalho-Silva, 2011; Oliveira, Lopes, Cabral, & Eberlin, 2006; Rufino et al., 2010). The nutritional and therapeutic value is mainly due to the presence of bioactive compounds, secondary metabolites, which have potential effects on human health (Oliveira et al., 2006).

Bioactive compounds occur in small amounts in foods and are considered as non-nutritional but vital ingredients for the maintenance of human health (Patil, Jayaprakasha, Chidambara Murthy, & Vikram, 2009). Regarding the compounds contained in these fruits that could potentially lead to health benefits, polyphenols are present as major compounds (Schreckinger et al., 2010). In this context, anthocyanins belonging to the flavonoid family represent a group of pigments responsible for most of the colors in fruits, leaves, flowers, stems and roots of plants (Leite et al., 2011). Their spectrum of color varies from red to blue (Leite et al., 2011; Prior & Wu, 2006) and also presents itself as a mixture of both color shades resulting in purple-black tones. Other compounds with health benefits have been described on scientific literature such as tocopherols, glucosinolates, organosulphur compounds, sterols, saponins, stilbenes and tannins (Kris-Etherton et al., 2004). In general, these compounds present anti-inflammatory and antioxidant effects (Dossett, Lee, & Finn, 2010; Dziri et al., 2012; Kang et al., 2011; Leite et al., 2011).

In this context, this article summarizes the foremost bioactive compounds and the health properties of the exotic tropical red–black berries, specifically *Euterpe oleracea*, *Eugenia uniflora*, *Myrciaria cauliflora*, *Myrciaria dubia*, *Syzygium cumini*.

2. Characteristics of exotic tropical red–black berries

The Table 1 shows the common name, scientific name, family, origin, bioactive compounds and main health benefits of the tropical berries. These fruits do not occur in all tropical countries due to varying climate and soils. However, depending on the time of year, it is possible to find these fruits at fairs and specialized markets, attended by people interested in typical tropical food. These fruits are usually seasonal and grow at tropical climate, where the harvest occurs mainly during the warmer months of the year.

The Table 2 shows the levels of vitamin C, total anthocyanins and total phenolics of the fruits analyzed in this contribution. Furthermore, Fig. 1 shows the chemical structures of the main bioactive compounds described such as anthocyanins (Fig. 1A) and other phenolic compounds (Fig. 1B–D).

3. *E. oleracea* (Açaí)

3.1. *Botanical description*

Açaí palm is the commonly used name for the specific specie of palm tree known as *E. oleracea* Martius. This palm is native of South America and grows mainly in Brazil, Colombia and Suriname, and in the Amazonian flood lands (Schauss et al., 2006). Palm tree present an edible small purple-black berry

Table 1 – Common name, scientific name, species family, bioactive compounds and health benefits of exotic tropical red–black berries.

Common name	Scientific name/ Family	Bioactive compounds	Health benefits
Açaí, Asai palm, Azaí Huasaí, Manaca palm	*Euterpe oleracea*/ Arecaceae	Anthocyanins, flavonoids, phenolic acids, procyanidin, lignans, stilbenes	Increase plasma antioxidant capacity Mertens-Talcott et al. (2008), decrease of oxidative stress Noratto et al. (2011) Anti-inflammatory effects Kang et al. (2011), oratto et al. (2011) Improvement of endothelial function Michalska et al. (2010), Rocha et al. (2007) and platelet aggregation Michalska et al. (2010) Ameliorating properties over metabolic syndrome de Oliveira et al. (2010), Udani et al. (2011) Anti-allergic Horiguchi et al. (2011) and anticancer properties Del Pozo-Insfran et al. (2006)
Pitanga, Brazilian cherry, Ñangapirí	*Eugenia uniflora*/ Myrtaceae	Anthocyanins, carotenoids, flavonols	Anti-diarrheic, diuretic, anti-rheumatic, anti-febrile and anti-diabetic Oliveira et al. (2006) Antimicrobial activity against *S. aureus*, *L. monocytogenes*, *C. lipolytica* and *C. guilliermondii* Victoria et al. (2012), anti-Trypanosoma Santos et al. (2012) β-adrenergic induced hypotension in rats heart Consolini and Sarubbio (2002)
Jaboticaba, Guapurú, Uva de árbol, Brazilian grape tree	*Myrciaria cauliflora*/ Myrtaceae	Anthocyanins, ellagic and gallic acid, carotenoids, depsides, tannins, rutin, vitamin C	Antioxidant potential increase in rats plasma Leite et al. (2011) Anti-inflammatory, against asthma and anti-diarrhea Lima et al. (2008), Reynertson et al. (2006) Inhibition of IL-8 production Reynertson et al. (2006) Antiproliferative effects against tumor cells lines Leite et al. (2012) Protective effect in cardiovascular disease and type 2 diabetes mellitus Lenquiste et al. (2012)
Camu-camu, Cacari, Camocamo	*Myrciaria dubia*/ Myrtaceae	Anthocyanins, ellagic acid, flavan-3-ols, vitamin C	High antioxidant capacity Rufino et al. (2010) Inhibition of LPS-induced NO release in RAW 264.7 cells Yazawa et al. (2011) Decrease of oxidative stress and anti-inflammatory Inoue et al. (2008)
Jambolão, Black plum	*Syzygium cumini*/ Myrtaceae	Anthocyanins, ellagic acid, quercetin, rutin, vitamin C	Antiscorbutic and diuretic features Benherlal and Arumughan (2007), Gordon et al. (2011) Numerous pharmacological features Baliga et al. (2011) Antidiabetic effects Baliga et al. (2011), Benherlal and Arumughan (2007), De Bona et al. (2011), Gordon et al. (2011), Teixeira et al. (1997), Teixeira et al. (2000)

Table 2 – Bioactive compounds in exotic tropical red–black berries.

Scientific name	Total phenolic (dry matter)	Total anthocyanins (fresh matter)	Vitamin C (fresh matter)
Euterpe oleracea	31.2 mg GAE/100 g Kang et al. (2012)	282–303 mg/100 g de Rosso et al. (2008)	84 mg/100 g Rufino et al. (2010)
Eugenia uniflora	4140–5810 mg FAE/100 g Celli et al. (2011)	26 mg/100 g Lima et al. (2002)	21.5 mg/00 g Freyre et al. (2000)
Myrciaria cauliflora	3160 mg GAE/100 g Reynertson et al. (2008)	58.1 mg/100 g Rufino et al. (2010)	238 mg/100 g Rufino et al. (2010)
Myrciaria dubia	1161 mg GAE/100 g Akter et al. (2011)	42.2 mg/100 g Rufino et al. (2010)	1882 mg/100 g Rufino et al. (2010)
Syzygium cumini	787 mg GAE/100 g Gordon et al. (2011)	93.3 mg/100 g Rufino et al. (2010)	112 mg/100 g Rufino et al. (2010)

FAE, ferulic acid equivalents; GAE, gallic acid equivalents.

which, at complete maturity, reaches 10–12 mm diameter. The pulp of this fruit is largely consumed as food, and present an unusual flavor similar to raspberries with a nutty taste (Gallori, Bilia, Bergonzi, Barbosa, & Vincieri, 2004).

3.2. *Bioactive compounds*

It has been reported that the Açaí fruit pulp presents 31.2 mg of gallic acid equivalents (GAE)/100 g dry matter (DM) (Kang et al., 2012). It is significantly rich in polyphenol, presenting mainly anthocyanins at 282–303 mg/100 g fresh weight (FW) (de Rosso et al., 2008) (Table 2), cyanidin-3-glucoside (de Rosso et al., 2008; Del Pozo-Insfran, Brenes, & Talcottt, 2004; Gallori et al., 2004; Heinrich, Dhanji, & Casselman, 2011; Pacheco-Palencia, Talcott, & Duncan, 2009; Ribeiro et al., 2010; Schauss et al., 2006) and cyanidin-3-rutinoside (de Rosso et al., 2008; Gallori et al., 2004; Heinrich et al., 2011; Pacheco-Palencia et al., 2009; Ribeiro et al., 2010; Schauss et al., 2006). Other anthocyanins (Fig. 1A) that have been isolated are: cyanidin-3-acetylhexose (de Rosso et al., 2008), cyanidin-3-arabinoside (Heinrich et al., 2011), cyanidin-3-sambubioside (Heinrich et al., 2011; Schauss et al., 2006), peonidin-3-rutinoside (de

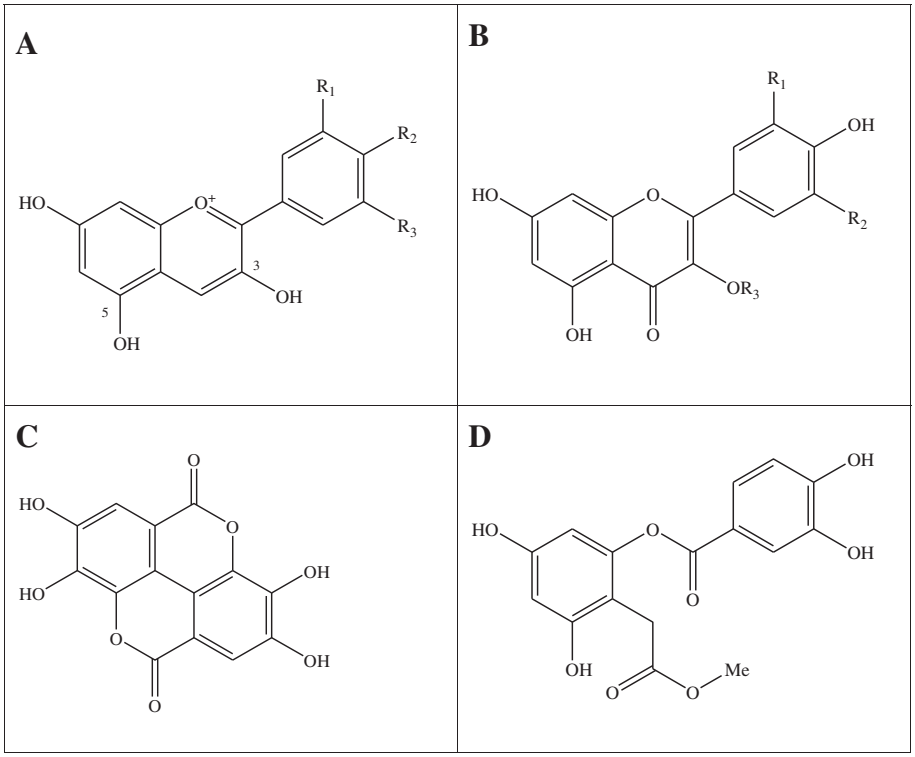

Fig. 1 – Chemical structure of phenolic compounds. (A) Pelargonidin: R_1 = H; R_2 = OH; R_3 = H, Cyanidin: R_1 = OH; R_2 = OH; R_3 = H, Delphinidin: R_1 = OH; R_2 = OH; R_3 = OH, Peonidin: R_1 = OMe; R_2 = OH; R_3 = H, Petunidin: R_1 = OMe; R_2 = OH; R_3 = OH, Malvidin: R_1 = OMe; R_2 = OH; R_3 = OMe, Glycosilation at 3 and 5 position, Adapted from Prior and Wu, 2006. (B) Kaempferol: R_1 = H; R_2 = H; R_3 = H, Myricetin: R_1 = OH; R_2 = OH; R_3 = rhamnose, Quercetin: R_1 = OH; R_2 = H; R_3 = H, Quercitrin: R_1 = OH; R_2 = H; R_3 = rhamnose, Rutin: R_1 = OH; R_2 = H; R_3 = rutinoside, Adapted from Reynertson et al., 2008. (C) Ellagic acid. Adapted from Reynertson et al., 2008. (D) Jaboticabin. Adapted from Reynertson et al., 2006.

Rosso et al., 2008; Heinrich et al., 2011; Pacheco-Palencia et al., 2009; Schauss et al., 2006), peonidin-3-glucoside (de Rosso et al., 2008; Heinrich et al., 2011; Schauss et al., 2006) and pelargonidin-3-glucoside (de Rosso et al., 2008; Del Pozo-Insfran et al., 2004; Heinrich et al., 2011). Regarding flavonoids, the presence of rutin, apigenin diglucoside, luteolin diglucoside (Pacheco-Palencia et al., 2009), apigenin 6-glucoside, luteolin 8-glucoside (Ribeiro et al., 2010), homoorientin, orientin, taxifolin deoxyhexose (Gallori et al., 2004; Heinrich et al., 2011; Pacheco-Palencia et al., 2009; Schauss et al., 2006), taxifolin 3-rhamnoside (Ribeiro et al., 2010), isovitexin (Gallori et al., 2004; Heinrich et al., 2011; Kang et al., 2011; Pacheco-Palencia et al., 2009; Schauss et al., 2006), dihidrokaempferol 3-*O*-β-D-glucoside and its isomers (Kang et al., 2011), velutin, dihidroxy-7′,3′,5′-trimethoxyflavone (Kang et al., 2011), scoparin (Pacheco-Palencia et al., 2009; Schauss et al., 2006), (+)-catechin (Del Pozo-Insfran et al., 2004; Heinrich et al., 2011; Pacheco-Palencia et al., 2009; Ribeiro et al., 2010) and (−)-epicatechin (Del Pozo-Insfran et al., 2004; Heinrich et al., 2011; Pacheco-Palencia et al., 2009), also procyanidin dimers and trimers (Pacheco-Palencia et al., 2009), phenolic acids such as protocatechuic (Del Pozo-Insfran et al., 2004; Heinrich et al., 2011; Pacheco-Palencia et al., 2009), *p*-hydroxybenzoic, vanillic, syringic, ferulic (Del Pozo-Insfran et al., 2004; Heinrich et al., 2011; Pacheco-Palencia et al., 2009), gallic, benzoic (Del Pozo-Insfran et al., 2004; Heinrich et al., 2011; Ribeiro et al., 2010), *p*-coumaric, and elagic acid (Del Pozo-Insfran et al., 2004), stilbenes such as resveratrol (Schauss et al., 2006) has been documented.

3.3. *Health benefits*

The presence of a high quantity and variety of antioxidant compounds in this fruit is very promising regarding health benefits. As a matter of fact, it has been observed an increase in the antioxidant capacity in plasma after Açaí pulp and juice consumption by healthy volunteers (Mertens-Talcott et al., 2008). It has been shown that plant polyphenols modify molecular events towards an improvement in endothelial function and inhibition of platelet aggregation (Michalska et al., 2010). Therefore, these compounds could play a role in the prevention of cardiovascular disease. In this sense, it has been reported that an Açaí stone extract presented vasodilator effects in rats (Rocha et al., 2007). Also, it has been observed that Açaí pulp-isolated flavonoids presented an important antioxidant activity measured by oxygen radical absorbance capacity (ORAC), and also protective anti-inflammatory features against lipopolysaccharide (LPS) and oxidized low density lipoprotein (LDL) induced nuclear factor κB (NF-κB) activation in mouse macrophages, suggesting athero-protective effects (Kang et al., 2011). Moreover, it has been observed that polyphenolic extracts of Açaí protected human vascular endothelial cells upon oxidative stress and inflammation (Noratto, Angel-Morales, Talcott, & Mertens-Talcott, 2011).

Noratto et al. (2011) described that Açaí extracts inhibited the ROS production induced by hyperglycemic conditions, reverted the high glucose-induced NF-κB phosphorylation and its gene expression (coinciding with a prevention of elevated mRNA expression and secretion of interleukine – IL-6 and IL-8), prevented increasing levels of granulocyte macrophage colony-stimulating factor secretion, and induced an increased translocation and activation of pregnane X receptor (a key transcription factor for the expression of several antioxidant enzymes), which was traduced in augmented multidrug resistance protein 1 (MDRP1), catalase gene expression and glutathione-S-transferase activity.

Furthermore, it has been shown that Açaí extracts presented direct effects on epigenetics modulators, such as microRNAs (Noratto et al., 2011). It was observed that extracts of this fruit inhibit the glucose-stimulated expression of miR-146a, which has been reported to negatively regulate NF-κB, therefore reducing the capability to generate transcripts of IL-6 and IL-8. It was also observed that these extracts presented the capability to block the inducing effects of LPS on NF-κB signaling and on the expression of adhesion molecules, such as vascular cell adhesion molecule 1 (VCAM-1) intercellular adhesion molecule 1 (ICAM-1) and E-selectin. In this sense, Açaí extracts induced a dose–response increase in the expression of miRNA-126, a modulator of VCAM-1 which has been observed to correlate negatively with leukocyte adherence.

A preparation of Açaí has been assessed to modify metabolic disorder in overweight individuals (Udani, Singh, Singh, & Barrett, 2011). It was observed improvements regarding fasting glucose and insulin levels following a 30 day treatment. It was also noted a reduction in total cholesterol levels and amelioration in the post-prandial increase in blood glucose after a standardized meal. Moreover, it was reported that a chronic oral treatment with an Açaí seed extract presented ameliorating properties over metabolic syndrome features induced by a high fat diet intake in mice (de Oliveira et al., 2010), reducing plasma malondialdehyde (MDA) concentration, body weight, plasma triacylglycerol, total cholesterol, glucose levels, and insulin resistance. Furthermore, Açaí pulp improves lifespan of flies that were fed on a high fat diet (Sun et al., 2010), and the supplementation with Açaí pulp in a hypercholesterolemic diet prevented the appearance of high levels of blood cholesterol and LDL in rats (de Souza, Silva, Silva, Oliveira, & Pedrosa, 2010).

Furthermore, a slight anti-inflammatory effect was observed as suggested by lower C-reactive protein levels, and also a mild decrease in lipid peroxidation. In this sense, it has been described that extracts of this fruit are highly potent in reducing nitric oxide (NO) production of a mice macrophage cell line, which were accompanied with an inhibition in inducible nitric oxide synthetase (iNOS) mRNA expression (Matheus, de Oliveira Fernandes, Silveira, & de Sousa Menezes, 2006). In addition, Açaí extracts presented protective effects against cigarette smoke-induced emphysema in mice, related to higher antioxidant enzymes activities, reduced the leukocyte, macrophage and neutrophil infiltration into the pulmonary alveoli, and reduced the metalloelastase protein level, a macrophage-derived protein involved in the extracellular matrix breakdown in emphysemia (de Moura et al., 2011).

It has been reported that an açaí pulp pre-treatment inhibited the antigen-induced degranulation of primary culture mast cells isolated from IgE-sensitized mouse, suggesting that this fruit could have anti-allergic effects (Horiguchi et al., 2011), and that polyphenolic fractions of Açaí reduced proliferation and induced apoptosis of HL-60 leukemia cells (Del Pozo-Insfran, Percival, & Talcott, 2006).

On the other hand, a polysaccharide fraction isolated from Açaí fruits induced γδT cell activation in human, mouse and bovine *in vitro*. These cells have been shown to participate in effective innate immune response. *In vivo*, this Açaí fraction induced recruitment of myeloid cells and IL-12 secretion. All this evidence point out to a possible involvement of this fruit in the treatment of asthma and infectious diseases (Holderness et al., 2011).

4. *E. uniflora* (Pitanga)

4.1. *Botanical description*

The Pitanga or Brazilian cherry (*E. uniflora*) is a member of the *Myrtaceae* family. It is a native tree from Brazil that is widely distributed in South American countries (Bicas et al., 2011), such as Argentina, Paraguay and Uruguay (Consolini & Sarubbio, 2002). The fruit looks like a small pumpkin. It is globoid, 3 cm in diameter, and presents eight to ten longitudinal grooves (Bicas et al., 2011; Celli, Pereira-Netto, & Beta, 2011). Their color depends on the variety, but ranges from red to purple, and the fruit has an exotic flavor, sweet and sour taste (Lima, Mélo, & Lima, 2002). In Brazil, the Pitanga has an important economic interest since it has been used to produce juices, jellies, and fruit compotes.

4.2. *Bioactive compounds*

In a recent study, Celli et al. (2011) observed that the total phenolic content in red and purple Pitanga varieties was 4140 and 5810 mg FAE/100 g DW (Table 2), respectively. A high phenolic content was found in immature fruits and the ripening reduced the levels of these compounds. In addition, a high antioxidant activity was observed for unripe fruits. On the other hand, the amount of carotenoids increased with maturation. Lima et al. (2002) found higher carotenoids levels in pulp in mature Brazilian cherry (111 μg β-carotene equivalents/g FW) than in semi-mature pulp (98 μg β-carotene equivalents/g FW). The Pitanga contains 21.5 mg of vitamin C/100 g of fruit (Freyre, Baigorria, Rozycki, Bernardi, & Charpentier, 2000).

The Pitanga contains 26 mg/100 g of fruit of total anthocyanins (Lima et al., 2002) (Table 2). The identification of anthocyanins showed the presence of cyanidin-3-glucoside (Celli et al., 2011) and delphinidin-3-glucoside (Einbond, Reynertson, Luo, Basile, & Kennelly, 2004) (Fig. 1A). Moreover, the identification of flavonols showed the presence of myricetin 3-*O*-hexoside, myricetin 3-*O*-pentoside, myricetin 3-*O*-rhamnoside, quercetin 3-*O*-hexoside, quercetin 3-*O*-pentoside, quercetin 3-*O*-rhamnoside and myricetin deoxyhexoside-gallate (Celli et al., 2011), and kaempferol (Hoffmann-Ribani, Huber, & Rodriguez-Amaya, 2009) (Fig. 1B). The anthocyanin

content and total flavonols are major in peel (0.42% and 0.12% of FW, respectively) when compared to the pulp (0.03% and 0.02% of FW, respectively) (Lima et al., 2002). Nevertheless, the pulp corresponds to almost 80% of the whole fruit, which is the main form of commercialization (Bicas et al., 2011).

4.3. *Health benefits*

In Brazil, the essential oil extracted from Pitanga tree leaves has been used by the cosmetics industry for its astringent properties (Amorim, Lima, Hovell, Miranda, & Rezende, 2009). Nevertheless, the leaves from this berry have been used in Brazilian folk medicine as anti-diarrheic, diuretic, anti-rheumatic, anti-febrile and anti-diabetic agent (Amorim et al., 2009; Oliveira et al., 2006; Victoria et al., 2012).

Victoria et al. (2012) showed an antimicrobial activity against *Staphylococcus aureus*, *Listeria monocytogenes*, *Candida lipolytica* and *Candida guilliermondii* for Pitanga leaves. The authors demonstrated that a single oral dose of this essential oil (10–200 mg/kg) did not cause lethality or toxicological effects in mice (Victoria et al., 2012). Santos et al. (2012), described that *E. uniflora* presents anti-Trypanosoma activity, representing an interesting alternative to combat infectious diseases such as Chagas disease. Moreover, an ethanolic extract of Pitanga was used against two strains of *Escherichia coli* and the test showed that it was not inhibited in a clinically relevant form by the extracts (Coutinho, Costa, Falcao-Silva, Siqueira-Junior, & Lima, 2010).

On other hand, Consolini and Sarubbio (2002) reported that Pitanga aqueous crude extract has a dual effect on rat heart, since a hypotension feature was described related to β-adrenergic action, comprising a potential risk for patients who suffer from arrhytmias or cardiac failure. Thus, more studies are necessary to elucidate the effects of extracts and essential oil of Pitanga to confirm their pharmacological potential.

5. *M. cauliflora* (Jaboticaba)

5.1. *Botanical description*

The Jaboticaba (*M. cauliflora*) belongs to the *Myrtaceae* family. It is a grape-like fruit that is found extensively throughout Brazil, but especially in the Southeast (state of Minas Gerais, Rio de Janeiro, São Paulo and Espírito Santo). The berries are globoid, have 2–4 cm in diameter with one to four seeds (Barros, Finger, & Magalhães, 1996). Curiously their fruits are born directly from the old branches and trunks of the tree. When ripe, the skin fruit present dark purple or black color. Also it is thin, fragile, and astringent, and the pulp is white, sweet and with a gelatinous flesh. This fruit possess a great economic interest due to the many forms that the fruit is used (Clerici & Carvalho-Silva, 2011). Owing to its flavor, the berries are often eaten fresh. The Jaboticaba fruits are often used to produce juices, wines, liqueurs, vinegar, jellies, and fruit compotes (Clerici & Carvalho-Silva, 2011; Reynertson et al., 2006; Santos, Veggi, & Meireles, 2010). Moreover, the extraction procedure is of great importance for obtaining natural colorants (Santos et al., 2010). Its high content of anthocyanins is also an attractive feature (Rufino et al., 2010). However, the main limitation is its high perishability due to the high content of sugar and water, which is associated with a rapid decay and fermentation, and to a very short postharvest shelf-life (Barros et al., 1996).

Several species of Jaboticaba are distributed within the genus *Myrciaria*, such as *M. jaoticaba* and *M. tenella* (Reynertson et al., 2006), but the *M. cauliflora* is the most widespread specie in Brazil (Lima, Corrêa, Alves, Abreu, & Dantas-Barros, 2008). In Brazilian folk, the Jaboticaba has been used as a treatment for asthma, inflammatory bowel disease, diarrhea and hemoptysis (Lima et al., 2008; Reynertson et al., 2006).

5.2. *Bioactive compounds*

The Jaboticaba fruit contains tannins and cyanidin-3-glucoside (*M. cauliflora*) (Santos et al., 2010; Trevisan, Bobbio, & Bobbio, 1972) and peonidin-3-glucoside and its aglycone (*M. Jaboticaba*) (Trevisan et al., 1972). The polyphenolic composition of *M. cauliflora* extracts was identified for the first time by Reynertson et al. (2006). They detected 2-*O*-(3,4-dihydroxybenzoyl)-2,4,6-trihydroxyphenylacetic acid, pyranocyanin B, quercetin, isoquercitrin, quercimeritrin, quercitrin, rutin, myricitrin, cinnamic acid, *O*-coumaric acid, gallic acid, protocatechuic acid, methyl protocatechuate, and ellagic acid (Fig. 1C). In addition, a new depside was identified, namely the jaboticabin (Fig. 1D). Depsides are phenolic compounds, first time identified in the Myrtaceae, containing two or more monocyclic aromatic units linked by an ester bond. According to Reynertson et al. (2006) the jaboticaba is rich in anthocyanins, phenolic acids, and flavonoids and contains depsides with antiradical, anti-inflammatory, and cytotoxic activity. Therefore it is believed that this fruit has a strong potential to be developed as a functional food. Rufino et al. (2010) reported 58.1 mg/100 g of total anthocyanins (Table 2).

Reynertson, Yang, Jiang, Basile, and Kennelly (2008) investigated phenolic compounds in Jaboticaba fruit and reported them to be at 3160 mg GAE/100 g DW (Table 2). This data is similar to the one described by Santos et al. (2010). On the other hand, Rufino et al. (2010) reported 440 mg GAE/100 g FW.

Other bioactive compounds that were found in Jaboticaba fruit (in 100 g FW) are vitamin C (238 mg), total anthocyanins (93.3 mg) and total carotenoids (0.32 mg) (Rufino, Alves, Fernandes, & Brito, 2011; Rufino et al., 2010). These data suggest that the content of vitamin C in Jaboticaba is lower than in Acerola and Camu-camu (1357 and 1882 mg/100 g FW, respectively), but it is higher than Pintanga, Açaí, and Jambolão (21.5, 84 and 112 mg/100 g FW, respectively) (Table 2). Moreover, the contents of total anthocyanins and total carotenoids are similar to Camu-camu (Rufino et al., 2010).

Recently, Abe, Lajolo, and Genovese (2012) investigated the presence of ellagic acid among the twenty botanical families of this fruit. The ellagic acid is a powerful compound with antioxidant properties and high contents of this acid have been found in Jaboticaba (3.11 g/kg FW). Thus, the researchers suggested that Jaboticaba is a promising source of ellagic acid derivatives in the diet.

5.3. *Health benefits*

Regarding health benefits, Leite et al. (2011) evidenced a significant increase in the antioxidant potential of plasma (mea-

sured by ORAC and trolox equivalent antioxidant capacity assay – TEAC) in rats treated with 1% or 2% of Jaboticaba peel/kg of food. Reynertson et al. (2006) observed that extracts of Jaboticaba had a strong antiradical activity according to 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay and significantly inhibited chemokine interleukin IL-8 production in human SAE cells treated with cigarette smoke extracts. Moreover, the micronucleus test in Swiss mice showed that the jaboticaba peel extract showed antiproliferative effects against tumor cells lines (leukemia and prostate) and induced no DNA damage and caused no mutagenic effects (Leite et al., 2012). In another study, jaboticaba peel was incorporated in the high fat diet of mice that were fed for 10 weeks, and the results did not showed significant changes in weight gain, organs weight, body composition, serum glucose, glucose tolerance test, insulin tolerance test and leptin (Lenquiste, Batista, Marineli, Dragano, & Maróstica Jr., 2012). However, the authors suggested that the consumption of jaboticaba peel had a protective effect against cardiovascular disease and type 2 diabetes mellitus, suggested by an increase of HDL-cholesterol levels and lower values of HOMA-IR, respectively (Lenquiste et al., 2012). Thus, due the several compounds of this berry, it is a promising emerging functional food.

6. *M. dubia* (Camu-camu)

6.1. *Botanical description*

Among the exotic fruits of Amazon region (Colombia, Venezuela, Peru and Brazil) Camu-camu (*M. dubia*), a member of the *Myrtaceae* family, has been focus of several studies. Similar to Jaboticaba, the Camu-camu fruit, when unripe, presents a green color and during the ripening the berry gains a red-colored tonality. According to Yuyama (2011), the berries are globoid, 2.5 cm in diameter with a strong acid taste and the pulp is white, with citric flavor and gelatinous flesh. These berries are often used to produce juice, jelly, and ice cream, and possess a high concentration of ascorbic acid.

6.2. *Bioactive compounds*

Camu-camu fruits are considered the richest natural source of vitamin C in Brazil (Justi, Visentainer, Souza, & Matsushita, 2000). Due to their high level of this vitamin, the Camu-camu derivatives such as pulp, extract and juice are extensively exported to Japan and European Union markets (Akter, Oh, Eun, & Ahmed, 2011; Chirinos, Galarza, Betalleluz-Pallardel, Pedreschi, & Campos, 2010). The content of vitamin C is 20 times higher than Acerola and 100 times greater than lemon (Vidigal, Minim, Carvalho, Milagres, & Gonçalves, 2011). Due to it high nutritional value, the Amazon Research National Institute (INPA) introduced the seed of Camu-camu in the interior of Brazil, in Minas Gerais, São Paulo and Paraná states (Yuyama, 2011). Nevertheless, Justi et al. (2000) observed that the fruit grown in Paraná presented lower content of vitamin C (1400 mg/100 g in the pulp) than the one from the Amazon region (2400–3000 mg/100 g in the pulp). This suggests that different conditions influencing the development of this plant might modulate the levels of bioactive compounds. Furthermore, Chirinos et al. (2010) reported that total phenolic contents in Camu-camu depend on the maturity stages.

Different types of polyphenols such as anthocyanins (cyanidin-3-glucoside and delphinidin-3-glucoside), quercetin, quercitrin, rutin, myricetin, naringenin, catechin, kaempferol (Fig. 1B), ellagic acid (Fig. 1C) and eriodictyol are found in Camu-camu fruits (Akter et al., 2011; Chirinos et al., 2010; Reynertson et al., 2008; Rufino et al., 2010). The total phenolic content of dried Camu-camu is 1161 mg GAE/100 g DM (Akter et al., 2011) (Table 2). The ellagic acid and flavan-3-ols groups represent the main phenolic compounds in this berry (Chirinos et al., 2010). According to Rufino et al. (2010) the total polyphenols in aqueous-organic extracts is higher in Camu-camu fruits (11.615 mg GAE/100 g DM) when comparing with Acerola and Jaboticaba (10.280 and 3584 mg GAE/100 g DM, respectively). On the other hand, the total anthocyanins (42.2 mg/100 g FW) (Table 2) of Camu-camu are lower than Açaí and Jambolão (111 and 93.3 mg/100 g FW, respectively).

Different methods such as DPPH, 2,2-azinobis (3-ethylbenzothiazoline-6-sulfonic) acid radical (ABTS) and ferric reducing antioxidant potential (FRAP) are used to determine the antioxidant capacity of this fruit. According to Rufino et al. (2010), Camu-camu exhibited higher antioxidant capacity than Açaí, Acerola, Jaboticaba and Jambolão when used ABTS (153 μmol Trolox/g of fresh matter) and FRAP (279 μmol Fe_2SO_4/g FW) assays. In addition, Chirinos et al. (2010) reported a positive correlation between total phenolic content and DPPH antioxidant capacity ($r^2 = 0.931$) but not between ascorbic acid levels and DPPH antioxidant capacity ($r^2 = 0.190$), suggesting that the antioxidant capacity of the fruit is derived mainly from phenolic compounds.

6.3. *Health benefits*

Recently, Yazawa, Suga, Honma, Shirosaki, and Koyama (2011) reported that crude extracts of Camu-camu seeds suppressed the formation of edema in a dose-dependent manner in mice by oral administration. A similar effect was observed *in vitro*, whereas extracts of Camu-camu seeds in a dose-dependent manner inhibited the lipopolysaccharide (LPS)-stimulated NO secretion by murine RAW 264.7 macrophages. This Japanese research group suggests that the edema suppression was due to the presence of betulic acid. On the other hand, Inoue, Komoda, Uchida, and Node (2008) evaluated, in male smokers, the anti-oxidative and anti-inflammatory properties of Camu-camu juice (daily 70 mL of juice, which corresponds to 1050 mg of vitamin C) compared to a group that receive a daily supplement of vitamin C (1050 mg daily). After 7 days, oxidative stress markers (levels of urinary 8-hydroxy-deoxyguanosine and total reactive oxygen species) and inflammatory markers (serum levels of high-sensitivity C reactive protein, IL-6 and IL-8) decreased significantly in the Camu-camu group, while there was no change in the vitamin C group. The authors suggest that the effect of Camu-camu juice may be due to the existence of unknown antioxidant substances besides vitamin C. In addition, anthocyanins, total phenolics and carotenoids could have contributed to this effect.

7. *S. cumini* (Jambolão)

7.1. Botanical description

S. cumini (synonym *Eugenia jambola* or *Syzygium jambos* or *Eugenia cuminii*) commonly known as Jambolão (Portuguese) or black plum or Jamun belongs to the *Myrtaceae* family. It is originated from India and Southeast Asia but is also widespread in Brazil. Their edible fruits are astringent to taste (Zhang & Lin, 2009), ovoid in shape, 2–3 cm long, the peel has a purple to black color, and the pulp has a grayish white color and presents a big purple seed (Gordon, Jungfer, da Silva, Maia, & Marx, 2011). The juice of unripe Jambolão is often used to prepare vinegar and the ripe fruits are used to produce preserves, squashes and jellies (Zhang & Lin, 2009). In folk medicine, this fruit has been used as anti-scorbutic, diuretic and for the treatment of gastrointestinal diseases (Benherlal & Arumughan, 2007; Gordon et al., 2011). Nevertheless, the main use of the Jambolão fruit relates to anti-diabetic features (Benherlal & Arumughan, 2007; Gordon et al., 2011; Teixeira et al., 1997; Teixeira et al., 2000).

7.2. Bioactive compounds

The total anthocyanin content of the Jambolão (93.3 mg/100 g FW) (Table 2) is higher than in other fruits such as Acerola, Camu-camu and Jaboticaba (18.9, 42.2 and 58.1 mg/100 g FW, respectively), (Rufino et al., 2010; Rufino et al., 2011). The major anthocyanins found were delphinidin 3,5-diglucoside (45%), petunidin 3,5-diglucoside (32%), malvidin 3,5-diglucoside (15%), and cyanidin 3,5-diglucoside and peonidin 3,5-diglucoside (Faria, Marques, & Mercadante, 2011). The same order of anthocyanin composition was reported by Brito et al. (2007). Furthermore, Reynertson et al. (2008) identified ellagic acid, quercetin and rutin. Other bioactive compounds were found in Jambolão fruits such as vitamin C and carotenoids (112 mg and 0.51 mg/100 g FW, respectively) (Rufino et al., 2010).

It has been reported that total phenolic compounds in Jambolão fruit is 148.3 mg GAE/100 g (Faria et al., 2011) and 390 mg GAE/100 g (Benherlal & Arumughan, 2007), but in dry matter the content is 787 mg GAE/100 g (Gordon et al., 2011). However, the highest content of total phenols was observed in kernel (37,000 mg GAE/100 g DM) and pulp ethanol extract (34,000 mg GAE/100 g DM) (Benherlal & Arumughan, 2007). According to Benherlal & Arumughan, 2007 the kernel ethanolic extract, when compared to pulp and seed extracts, showed similar or better antioxidant activity than DPPH, superoxide and hydroxyl radical scavenging assays. On the other hand, Rufino et al. (2011) found modest values when comparing against the reports of other research groups, regarding polyphenol content in aqueous-organic extracts of this fruit (1117 mg GAE/100 g DM). Thus, the extraction methods of antioxidants may play a decisive role in the estimation of the polyphenol levels and consequently in the determination of the antioxidant activity. The Jambolão fruit showed a significant antioxidant activity that may be due to its compounds, such as antioxidant vitamins, phenolics, tannins and anthocyanins.

7.3. Health benefits

In an extensive review, Baliga, Bhat, Baliga, Wilson, and Palatty (2011) reported that Jambolão shows several pharmacological properties: antibacterial, antifungal, antiviral, anti-diarrheal, anti-allergic, antipyretic, antineoplasic, anti-inflammatory, chemopreventive, radioprotective, gastroprotective, hepatoprotective, free radical scavenging, cardioprotective, hypolipidemic and hypoglycemic. However, the main health benefits are those concerning the anti-diabetic effects. Before the discovery of insulin, Jambolão was used as a diabetes treatment (Baliga et al., 2011). In this regard, this fruit has been intensively investigated in both animal models (Teixeira et al., 1997) and clinical studies (De Bona et al., 2011; Teixeira et al., 2000). Moreover, De Bona et al. (2011) reported the use of the Jambolão leaf extract as an adjuvant for the treatment of diabetes. These authors suggested that Jambolão leaf extract *in vitro* reduced inflammation and oxidative stress, and improved the alterations in the adenosine deaminase and acetylcholinesterase activities. These enzymes play an important role in the regulation of insulin action on glucose metabolism. Moreover, jambolão leaf extract was able to increase the antioxidant status in type 2 diabetes patients. However, other studies did not find beneficial health effect (Teixeira et al., 1997; Teixeira et al., 2000).

8. Mechanism of the main biological activities

The polyphenols are the main compounds present in exotic tropical red–black berries that could potentially lead to health benefits. The anthocyanins belong to the flavonoid family and occur primarily as glycosides of their respective aglycone anthocyanidin (Prior & Wu, 2006). They have potential benefits to health, especially for their promising action on treatment of some diseases (Schreckinger et al., 2010). Numerous investigations have been focused on the health benefits of consumption of red–black fruit, claiming these as natural sources of bioactive compounds with highly promising antioxidant and anti-inflammatory characteristics (Baliga et al., 2011; Dossett et al., 2010; Kang et al., 2011; Leite et al., 2011; Mertens-Talcott et al., 2008; Santos et al., 2012; Victoria et al., 2012; Yazawa et al., 2011).

The oxidative stress and inflammation play a central role in the pathogenesis of chronic diseases, such as obesity, diabetes, cancer and atherosclerosis (Inoue et al., 2008). Free radicals are produced in organism as a result of several metabolic activities and have been associated with chronic diseases (Benherlal & Arumughan, 2007). Each polyphenol, such as anthocyanin, has different free radical-scavenging activities depending on their chemical structure (position, number, and types of substitutions) (Rice-Evans, Miller, & Paganga, 1997; Wallace, 2011). The chemical activities of anthocyanins in terms of their reducing properties occur through the donation of electrons or hydrogen to free radicals. They also can act as metal chelators, inhibiting the formation of free radicals catalyzed by transition metals (Rice-Evans et al., 1997). On the other hand, tropical red–black berries such as *E. oleracea*, *E. uniflora*, *M. cauliflora* and *M. dubia* contains cyanidin-3-

glucoside (Akter et al., 2011; Celli et al., 2011; de Rosso et al., 2008; Heinrich et al., 2011; Reynertson et al., 2008; Ribeiro et al., 2010; Rufino et al., 2010; Santos et al., 2010; Schauss et al., 2006), which had one of the highest oxygen radical absorbance capacity (ORAC) (Wang, Cao, & Prior, 1997). In addition, *S. cumini* seed extract enhanced the levels of reduced glutathione and the activity of natural antioxidant enzymes, such as glutathione S-transferase, superoxide dismutase and catalase (Arun, Prakash, Abraham, & Premkumar, 2011).

Several mechanisms have been proposed to explain the anti-inflammatory properties of polyphenols (Wallace, 2011). Wallace (2011) reported that anthocyanins present anti-inflammatory effects involved in protection from DNA cleavage, estrogenic activity, lipid peroxidation, enzyme inhibition and increase of cytokine production that regulates immune responses. Moreover, the cyclooxygenase (COX) and factor nuclear kappa B (NF-κB) gene expression have been associated with inflammatory process. Anthocyanins alter mRNA expression of COX and transcription activity of NF-κB (Kaume, Gilbert, Brownmiller, Howard, & Devareddy, 2012).

9. Conclusions

The review showed a rich and diversified composition of bioactive compounds in exotic tropical red–black berries. The bioactive compounds from these fruits exhibit a positive relationship with health benefits. The major difficulty to interpretate data concerning to health benefits of food is the inconsistence of the methodologies used. However, the present review showed that *E. oleracea*, *E. uniflora*, *M. cauliflora*, *M. dubia* and *S. cumini* demonstrate an important diversity of phytochemicals, mainly phenolic compounds and vitamin C. Though, the health benefits of consumption of these fruits, especially regarding to antioxidant activity, could not be the result of a single bioactive compound, but may arise from synergy among compounds. Thus the diary consumption of these fruits can contribute to improve the serum antioxidant status. On other hand, the knowledge of the bioactive compounds present in leaves, seed, pulp and hull of these fruits could contribute to a competitive agribusiness. Moreover, these fruits can be used to improve the bioactive compounds into food products to health promotion, such as supplements and nutraceuticals. The fruits reviewed make it a promising emerging functional food item.

Acknowledgement

The authors would like to thank to National Council for Scientific and Technological Development (CNPq) for the financial support (479093/2012-1).

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