

# An Update on the Biological Activities of *Euterpe edulis* (Juçara)

## Authors

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## ABSTRACT

The palm tree *Euterpe edulis*, known as juçara, produces spherical and purple fruits, similar to those of the *Euterpe oleracea* and *Euterpe precatoria* palm trees, from which the common name açaí originates. Juçara fruit has been gaining prominence in the scientific world for its interesting nutritional composition, which is rich in antioxidants, and for its sustainable production model. Recently, relevant biological activities have been associated with the juçara fruit, and its use in alimentation has become an important nutritional, environmental, and economic alternative. The aim of this review is to compile recent scientific data about the phytochemical characterization and biological activities of *E. edulis*. A review of the literature was conducted in two electronic databases, Medline and Science Direct. The eligibility criteria were as follows: phytochemicals characterize of the *E. edulis* fruits and evaluate biological effects *in vitro* or *in vivo* with pulp, extract, juice, or product of juçara fruits. Investigations were excluded if they used other parts of the plant (seeds), did not assess biological activities, or have tested methodologies for compound extraction. From the identified reports, 25 articles were eligible for this study. The promotion of health benefits related to juçara fruits seems to have improved antioxidant activity *in vivo*, benefits to lipid and glycemic profiles, and modulation of inflammatory status in experimental studies in animals.

## Introduction

Studies have reported that fruit consumption promotes protective effects on the body, especially because of the phenolic compounds found in them [1–3]. There is a growing interest in native and exotic fruits from tropical countries, particularly due to their nutritional composition, which includes high levels of anthocyanin (ACNs) [4–5].

Açaí comes from the *Euterpe* genus palm tree, a member of the Arecaceae family. The most popular species of palm trees which the açaí originates are *Euterpe oleracea* Martius and *Euterpe precatoria* Martius [6]. According Yamagichi et al. [6], only these two species are commercially used for their fruits. However, it is possible

that sometimes juçara is named açaí to make it commercially relevant, despite belonging to a different species of palm [7].

A native tree of the Atlantic Forest, the palm species *Euterpe edulis* Martius, popularly known as juçara (or jussara) and açaí-do-sol, has recently been gaining relevance in the scientific literature. The juçara palm produces a spherical purple fruit, with sensorial characteristics comparable to those of açaí, but with a better nutritional composition [8–12]. However, the excessive extraction of palm heart from the juçara tree has driven it to almost being extinction. For this reason, the sustainable exploitation of this species can make the use of the juçara fruit in alimentation a great nutritional, environmental, and economic alternative [8, 12, 13].

## ABBREVIATIONS

ACN	anthocyanin
AIN	American Institute of Nutrition
ALT	alanina aminotransferase
ApoE	apolipoprotein E
AST	aspartato aminotransferase
CAT	catalase
DPPH	radical 2,2-diphenyl-1-picrylhydrazyl
dwb	dry weight basis
FRAP	ferric reducing antioxidant potential
fwb	fresh weight basis
GPx	glutathione peroxidase
HDL-C	high-density lipoprotein cholesterol
IFN	interferon
IL-6	interleukin 6
IL-1 $\beta$	interleukin 1 $\beta$
LDL-C	low-density lipoprotein cholesterol
NF- $\kappa$ B	nuclear factor kappa B
ORAC	oxygen radical absorbance capacity
RDA	recommended dietary allowance
ROS	reactive oxygen species
SOD	superoxide dismutase
sVCAM-1	soluble vascular cell adhesion molecule-1
TC	total cholesterol
TNFR1	tumor necrosis factor receptor 1
TNF- $\alpha$	tumor necrosis factor alpha
UCP-1	uncoupling protein 1

Studies about the biological effects of the *E. edulis* palm fruit are recent and seem promising. They highlight its antioxidant, anti-inflammatory, and cardioprotective effects [14–18]. In 2016, the chemical constituents and botanical aspects about *E. edulis* were compiled in Schulz's review [12].

To the best of our knowledge, the present review is the first work that aims to summarize the phytochemical characterization and especially biological activities focusing on the *E. edulis* fruits. *E. edulis* originates from a pulp that some researchers consider very similar to açai, with interesting nutritional composition. Biological effects related to juçara fruits are emerging in the scientific literature, so it is relevant to compile this data to be aligned with the advancing scientific paths.

The research was conducted on the Medline (via PubMed) and Science Direct (via Scopus) online databases. The articles selected for this study had the following eligibility criteria: without restriction of written language, they had to evaluate some effect of biological relevance *in vitro*, *in vivo*, or by clinical trials, with administration of pulp, juice, or extract of juçara fruits; they had to evaluate the phytochemical characterization of juçara fruits and be published in the last five years. The following elements were not considered in this review: studies that evaluated methodologies which optimized extraction of fruit compounds, studies that focused on botanical aspects, and those that evaluated other plant parts (seeds or seed products). A flow chart of the selection of studies is given in the Supporting Information.

The research was conducted between May 2016 and August 2017. Titles and abstracts of the articles were revised, and when the information was not clear, the full text was accessed. Twenty-five articles were selected as eligible for this study, which addressed antioxidant properties, effect on metabolic parameters, anti-inflammatory, and other effects.

## Chemical Characterization

Chemical composition of juçara fruit has been demonstrated in several studies. The juçara fruit must be processed before being consumed. After selection and washing, juçara fruits are macerated and mixed with different amounts of water, where the pulp (epicarp and mesocarp) is separated from the seeds. This process results in a creamy, dark purple liquid with a characteristic flavor, commonly called pulp [8, 10]. The way of juçara fruit is prepared may result in different chemical compounds [8].

The pulp or drink produced from juçara fruit has important nutritional properties for human nutrition. It can be regarded as an energy source, fiber, ACN, minerals, and unsaturated fatty acids [8, 10].

The juçara pulp presents high energy density (0.8 kcal/mL), mainly by the presence of lipids [11]. Lipids are the main macronutrients of juçara pulp according some authors [8, 11, 19]. Depending on the palms growing region and during the ripening cycle, this content can have a great variation of lipids, around 18.5–44.1% [8] or from 7.1 to 22.1 g/100 g on a dry weight basis (dwb) [19], showing a large variation during ripening. Regarding the distribution of fatty acids, the juçara pulp has around 30% of saturated, 35% of monounsaturated, and 35% of polyunsaturated, according to what region in the southern Brazil, state of Santa Catarina, that the fruit grew [8, 19]. The fatty acids in larger quantities are unsaturated, representing about 50–70% of the total lipid fraction. On a dwb, the proportions of oleic acid and linoleic acid were between 44% and 55% and between 18% and 25%, respectively [8]. Schulz et al. [19] also found oleic acid as the main fatty acid in dried samples of juçara, representing around 35–42% of the total fatty acids.

## Minerals

Few studies have identified and quantified minerals in juçara fruit. The most minerals are found in the pulp of these fruits [11].

Da Silva et al. [20] showed a large amount of magnesium in samples of juçara fruit, 974.4 mg/100 g (dwb). However, other studies showed much lower amounts of this mineral, 183 mg/100 g (dwb) [19], 98.0 mg/100 g (dwb) [17], and 47.4 mg/100 g (dwb) [11].

Considering the evaluation of copper, the values found by Da Silva et al. [20] and Novello et al. [17] were 9930  $\mu$ g/100 g and 1110  $\mu$ g/100 g on a dwb, respectively. These values were sufficient to reach the RDA values for this mineral (900  $\mu$ g/day) [21]. Inada et al. [11] demonstrated below 500  $\mu$ g/100 g (dwb).

Although Da Silva et al. [20] showed a large amount of zinc (27.1 mg/100 g dwb), other studies showed lower levels, followed by Schulz et al. [19] with 2.8 mg/100 g (dwb), Novello et al. [17] with 2.0 mg/100 (dwb), and Inada et al. [11], with 0.9 mg/100 g (dwb).

Studies demonstrated interesting quantities of manganese by Da Silva et al. [20] and Novello et al. [17], 33.6 mg and 23.9 mg/100 g (dwb), respectively, while Schulz et al. [19] and Inada et al. [11] showed lower values of 8.4 and 3.0 mg/100 g (dwb), respectively. Even these differences all values are higher than the adequate intake values for men (2.3 mg/day) and women (1.8 mg/day) [21].

Values found for iron are worth mentioning. Da Silva et al. [20] found much higher quantity of this mineral, 65.3 mg/100 g (dwb), compared with the amount presented by other studies, 7.2 mg [19], 5.2 mg [17], and 4.3 mg [11] in 100 g (dwb). With the exception of the amount showed by Da Silva et al. [20], which exceeds the RDA values (men: 8 mg/d; women: 18 mg/d) [21], in 100 g, the others studies have demonstrated to reach almost half of these daily recommendations. Despite the amount of iron found in fruits, their bioaccessible fractions evaluated *in vitro* seem to be low according to Schulz et al. [22], from 0 to 29.5% with rates increasing according to the advancement of ripening.

Other nutrients relevant are potassium and calcium. Great amounts of potassium were observed: 998.67 to 1325.88 mg depending of maturation stage (0–69 d [22]) followed by 1291.5 mg [19], 1090.8 mg [20], 892.2 mg [17], and 419.1 mg [11] (all values in 100 g on a dwb). Regarding calcium, Da Silva et al. [20] found 1040.6 mg/100 g (dwb) and demonstrated that it exceeds the RDA value (men and women: 1000 mg/day) [21], while Schulz et al. [19] showed approximately half the RDA value for this mineral: 596.7 mg/100 g (in the stage 7 of maturation, which corresponds to 69 days after the red berries appeared in bunches). Zero to 69 d evaluated in seven stages [22]. Novello et al. [17] and Inada et al. [11] showed much lower values, 76.4 mg and 100.0 mg/100 g (dwb), respectively. In addition, calcium presented great bioaccessibility (14.3–65.5%) compared with other minerals evaluated in different stages of ripening (0–69 d) [22].

For phosphorus, studies show great disparity values, while Da Silva et al. [20] presents 1324.5 mg and Inada et al. [11] and Novello et al. [17] showed 41.2 and 26.7 mg/100 g (dwb), respectively. For sodium, 397.3 mg and 149.3 mg were the highest values found by Silva et al. [20] and Novello et al. [17] per 100 g (dwb), respectively, while Inada et al. [11] and Schulz et al. [19] showed much lower values, 17.3 mg and 14.2 mg per 100 g (dwb), respectively.

## Vitamins

According to Rufino et al. [23], the amount of vitamin C presented in juçara fruits, compared to other tropical fruits, is considered modest in quantities of 100 g of fresh weight basis (fwb). The vitamin C variability may occur due to soil characteristics, weather, agricultural practices, and ripeness stage, as well as due to the harvest, transport, storage, and the depulping process. However, the vitamin C content in juçara pulp is similar to other juices of non-citrus fruits such as blackberry, cranberry, and plum (4–11 mg/100 mL) [11].

Rufino et al. [23] reported the amount of 1900 µg/100 g (fwb) of the total carotenoids in juçara fruit collected in Santa Catarina, southern Brazil. In contrast, values of total carotenoids founded by Silva et al. [13] and Inada et al. [11] (737 µg and 414 µg/100 g fwb, respectively) were lower. Consonant to the classification of

carotenoid sources proposed by Britton and Khachik [24] ([per 100 g/fwb]: low: 0–100 µg; moderate: 100–500 µg; high: 500–2000 µg; and very high: >2000 µg), juçara pulp may be considered a high or moderate source of carotenoid.

Silva et al. [13] showed a higher value of retinol activity equivalent (27.8 µg/100 g fwb) compared to the study of Inada et al. [11] (7 µg/100 g dwb).

Novello et al. [17] in an experimental study assessed the amount of  $\beta$ -carotene in lyophilized juçara extract with 23.9 µg per kilogram of extract, while Inada et al. [11] reported 86 µg/100 g (dwb) of  $\beta$ -carotene in the whole fruit. This amount is higher than the amount of  $\beta$ -carotene showed in lyophilized extract of açai (*E. oleracea*) by Schauss et al. [25], around 3 µg/100 g dwb.

## Phenolic Compounds

Juçara palm provides a fruit with high nutritional value, which contains bioactive compounds, such as ACNs, non-ACN flavonoids, and phenolic acids, which are associated with potent biological activities [12]. The ► **Table 1** summarizes the biological activities tested in *E. edulis* fruit.

Silva et al. [13] showed a great value of 4087 mg/100 g dwb to soluble phenolics in juçara pulp with fruits collected in the southeast of Brazil (São Paulo) in its mature stage. Inada et al. [11] found lower content of soluble phenolics (1695 mg/100 g dwb) consisting of 95% of the total content of phenolic compounds, while insoluble compounds comprise 5%. Juçara pulp sample was produced by Juçari® processing company, 2012 crop, also located in the southeast of Brazil (Rio de Janeiro). Bicudo et al. [10] found much lower values of soluble and insoluble phenolic compounds (244 mg/100 g dwb). The fruits were 2012 crop and were classified into three maturity stages according to their external color.

The profile of phenolic acids in juçara fruit consists in gallic acid, protocatechuic, p-hydroxybenzoic, vanillic, chlorogenic, caffeic, syringic, p-coumaric, sinapinic, and ferulic acids [9–11, 19]. Inada et al. [11] were the first to identify the phenolic acids m-coumaric, transcinnamic, 4-hydroxyphenylacetic, and 3,4-dihydroxyphenylacetic in juçara pulp.

The amount of phenolic acids varies during the ripening stage in juçara fruits. The majority phenolic acid in all ripening stages of juçara fruit was protocatechuic acid [19]. Other authors reported that the ripening of the fruit and the geographic location may interfere in the phenolic compounds of the fruits of palm juçara [8, 10].

The main constituents of the phenolic compounds in juçara pulp are the ACNs [8–10]. The ACNs found in greater amounts in juçara fruits are cyanidin-3-rutinoside followed by cyanidin-3-glucoside [8, 10, 11, 13–15, 17, 26]. However, De Brito et al. [27] identified a greatest amount of cyanidin-3-glucoside (53%) and cyanidin-3-rutinoside (46%).

Others subtypes of ACNs were identified in the samples of juçara by several authors: cyanidin-3-sambunside [16, 17, 27], pelargonidin-3-glucoside [16, 27], pelargonidin-3-rutinoside [17, 27], peonidin-3-rutinoside [13, 16, 17], peonidin-3-glucoside [10], and delphinidin-3-glucoside [16, 17].

In addition, the study performed by Peron et al. [28] reported that ACNs from juçara degraded more slowly than from grapes (Italy type) after temperature effect (50 and 90 °C). Although phe-

► **Table 1** Biological activities tested in *E. edulis* fruit.

References	Biological activity evaluated	Total phenolics (TP) and Anthocyanins (ACN) evaluated	Results
[22]	Bioaccessibility of bioactive compounds potential of juçara fruits exposed to <i>in vitro</i> gastrointestinal digestion	TP: 79.98 mg (before simulating gastrointestinal digestion) TP: 19.71 mg (after simulating gastrointestinal digestion) (100 g/ dwb)	Mineral and phenolic compounds content started with 1325.9 and 22.9 mg/100 g respectively, and after <i>in vitro</i> digestion, the maximum values were 556.7 and 14.43 mg/100 g (dwb).
[19]	Antioxidant activity in seven different stages of fruit ripening	ACN: 18.76 mg/100 g ± 2.9 (first stage) to 634.26 mg/100 g ± 195.02 (sixth stage) (fwb)	DPPH radicals were higher in the extracts of stages 5 (3.5 ± 0.5 mg/mL) and 6 (3.0 ± 0.8 mg/mL). The antioxidant activity by FRAP also showed higher activity in maturation stage 6. FRAP and DPPH were directly correlated with the ripening process.
[9]	Protective antioxidant effect on Vero cell culture	ACN: ranging 91.52–236.19 mg/100 g (dwb)	Defatted pulp showed the highest total monomeric anthocyanin content versus lipid fraction extracts and presented a higher antioxidant activity, too.
[10]	Antioxidant properties	TP: ranging 81.69–49.09 mg/g (dwb) ACN: ranging 91.52–236.19 mg/100 g (dwb)	Radical scavenging capacity was DPPH, 655.89–745.32 µmol TE/g and oxygen radical absorbance capacity ORAC, 1088.10–2071.55 µmol TE/g. These authors considered the fruit a new source of antioxidants.
[15]	Antioxidant activity and lipid peroxidation in healthy individuals	ACN: 2033.7 ± 28.1 mg/450 mL Cyanidin-3-glucoside: 102.9 ± 4.0 mg/450 mL (fwb) Cyanidin-3-rutinoside: 480.5 ± 5.9 mg/450 mL (fwb)	Dose: 450 mL, before and 1 h, 2 h, and 4 h after of single intake by healthy individuals. Interaction on the lipid peroxidation measured by lipid hydroperoxides, with decreasing values over time and treatment effect on GPx.
[11]	Antioxidant activity	TP: 1783 Cyanidin-3-glucoside: 425 ± 8 Cyanidin-3-rutinoside: 1255 ± 17 (mg/100 g on a dwb)	Phenolic compounds are the main contributors to the antioxidant activity of juçara fruit
[14]	Effect on hepatic oxidative and inflammatory biomarkers in mice	ACN: 25.83 Cyanidin-3-glucoside: 9.52 Cyanidin-3-rutinoside: 16.30 (mg/g on a dwb)	The rats that received aerobic moderate-intensity exercise training (EXA and EX groups) showed a significant decrease in SOD activity, but no effect of diet or interaction on SOD was demonstrated. No effect on TC, triacylglycerol and HDL-C.
[16]	Antioxidant potential and effect on genetic dyslipidemia and hepatic steatosis in mice	ACN: 301.4 mg/100 g (dwb)	The groups treated with 2%, 6%, and 10% of juçara extract and 2% α-tocopherol acetate showed a decreased CAT. The group of animals received diet added 6% juçara extract showed lower SOD activity than the other groups. Group that received 10% of juçara added in diet decreased LDL-C and triacylglycerol concentrations.
[17]	Antioxidant and antiatherogenic activities both <i>in vivo</i> (mice) and <i>in vitro</i>	ACN: 25.83 Cyanidin-3-glucoside: 9.52 Cyanidin-3-rutinoside: 16.31 (g/kg/dwb)	The groups that received juçara, 2% and 6%, showed a significant decrease in the enzymatic activities of CAT and SOD when compared to the positive control group. Animals that had 6% of juçara added in diet lowered the concentrations of LDL-C and TC.
[18]	Effect on glucose tolerance in mice	Data not shown	The animal groups that received 0.5% of juçara improved glycemic response.
[53]	Metabolic parameters, anti-inflammatory effect and the expression of UCP-1	ACN: 262.4 ± 8.6 Cyanidin-3-glucoside: 71.4 ± 2.1 Cyanidin-3-rutinoside: 191.0 ± 6.5 TP: 415.1 ± 22.3 (mg/100 g on a fwb)	The offspring, which the maternal diet was added with 0.5% juçara freeze-dried, decreased triacylglycerol, blood glucose, and weight gain. In addition, the same group increased the anti-inflammatory marker IL-10 and increased the UCP-1 expression in the brown adipose tissue.
[38]	Antioxidant effect, metabolic parameters, and anti-inflammatory effect	Two major anthocyanins Cyanidin-3-glucoside and cyanidin-3-rutinoside, respectively, but were not quantified	The G3 (commercial diet plus 10% of lyophilized juçara pulp) and G4 (commercial diet plus 10% of lyophilized and defatted juçara pulp) groups decreased lipid peroxidation. The G4 decreased the enzymatic activity of CAT, GST, and SOD, and still decreased serum levels of TC. The G4 had lower expression of pro-inflammatory cytokines tissue but also was associated with decreased anti-inflammatory biomarkers.

continued

► **Table 1** Continued

References	Biological activity evaluated	Total phenolics (TP) and Anthocyanins (ACN)	Results
[39]	Antioxidant and toxic effects on cardiac and renal tissues of Wistar rats	Data not shown	The main results were a significant increase in CAT activity in tissues of animals fed with cafeteria diet plus 5% of <i>E. edulis</i> lyophilized extract, plus 10% of <i>E. edulis</i> lyophilized extract and 10% <i>E. edulis</i> defatted lyophilized extract. No effect was reported on lipid peroxidation in cardiac and renal tissues after juçara intervention.
[32]	Effects of juçara bioproducts (lyophilized pulp, defatted lyophilized pulp, and oil) on nonalcoholic fatty liver disease induced by a high-fat diet in rats	TP (mg GAE/g) (dwb): 4.10 ± 0.13 (lyophilized pulp) 4.95 ± 0.07 defatted lyophilized pulp ACNs (mg GAE/g) (dwb): 2130 ± 114 (lyophilized pulp) 3,121 ± 139 defatted lyophilized pulp	The groups that received pulp (defatted or not) attenuated the steatosis and lipid peroxidation in tissues, while the oil did not show the same effect. The most promising product appeared to be lyophilized pulp defatted, possibly due low lipid content and high ACNs and phenols
[60]	Inflammatory state in offspring for which maternal diet contained juçara pulp	ACN: 262.4 ± 8.6 Cyanidin-3-glucoside: 71.4 ± 2.1 Cyanidin-3-rutinoside: 191.0 ± 6.5 TP: 415.1 ± 22.3 (mg/100 g on a fw)	Adding 0.5% of juçara in maternal diet restored the fecal content of <i>Bifidobacterium</i> spp. and increase colonic ZO-1 mRNA expression. Still, the same group decreased pro-inflammatory markers and increased anti-inflammatory mediators.
[52]	The effect of juçara supplementation in the maternal diet on the inflammatory state of the colon in offspring exposed to perinatal and on lipid profile and glucose	Data not shown	The groups of (pregnant or lactating) rats that receiving diet with 0.5% juçara (CJ and TJ) decrease pro-inflammatory. In contrast, the cytokine anti-inflammatory was higher in the CJ group than in the T group. Still the groups that received juçara freeze-dried powder (control diet with 0.5% of juçara added) decreased the TC and triglycerides. The groups that received juçara (CJ and TJ) decreased serum levels of glucose.
[26]	<i>In vitro</i> fermentation by human colonic microbiota	TP: 3474 ± 98.0 Cyanidin-3-rutinoside: 966 ± 54.9 Cyanidin-3-glucoside: 322 ± 43.7 (mg/100 g on a dwb)	The intestinal microbiota <i>in vitro</i> was modulated by juçara pulp, which was capable of altering the population of the microbiota and short-chain fatty acids production.
[65]	Added juçara pulp and commercial probiotic ( <i>Lactobacillus acidophilus</i> ) in yogurt to evaluate the survival probiotic in storage and after gastric and enteric digestion <i>in vitro</i>	Data not shown	Juçara pulp seems a good strategic for the production of yogurts increasing the resistance of probiotics for until 14 d of storage even after the stimulation of gastrointestinal conditions. It is suggested with this study that polyphenols in particular ACNs may have improved the probiotic viability.

nolic compounds still found after temperature effect, the 90 °C decreased the antioxidant activity of the extracts. However, in spite of these results, it is emphasized that the ingestion of juçara is preferably in its fresh form, after processing the fruits with addition of water.

A recent research investigated the major ACNs and non-ACN phenolic compounds in juçara extracts using ultra performance liquid chromatography-mass spectrometry. This study found high amounts of ACN, about 26 mg/g dwb from a total of 31 mg/g dwb of phenolic compounds. Cyanidin-3-O-rutinoside was the most abundant ACN (73% of the total phenolic compounds content). Other phenolic compounds found in the extract were cyanidin-3-O-glucoside, pelargonidin-3-O-glucoside, quercetin, rutin, myricetin, kaempferol, kaempferol-3-O-rutinoside, luteolin, apigenin, catechin, ellagic acid, and 4,5-dicaffeoylquinic acid. The authors considered juçara a promising source of polyphenolics, mainly ACNs [29].

The chemical structures of ACNs known in juçara fruit are presented in ► **Fig. 1**.

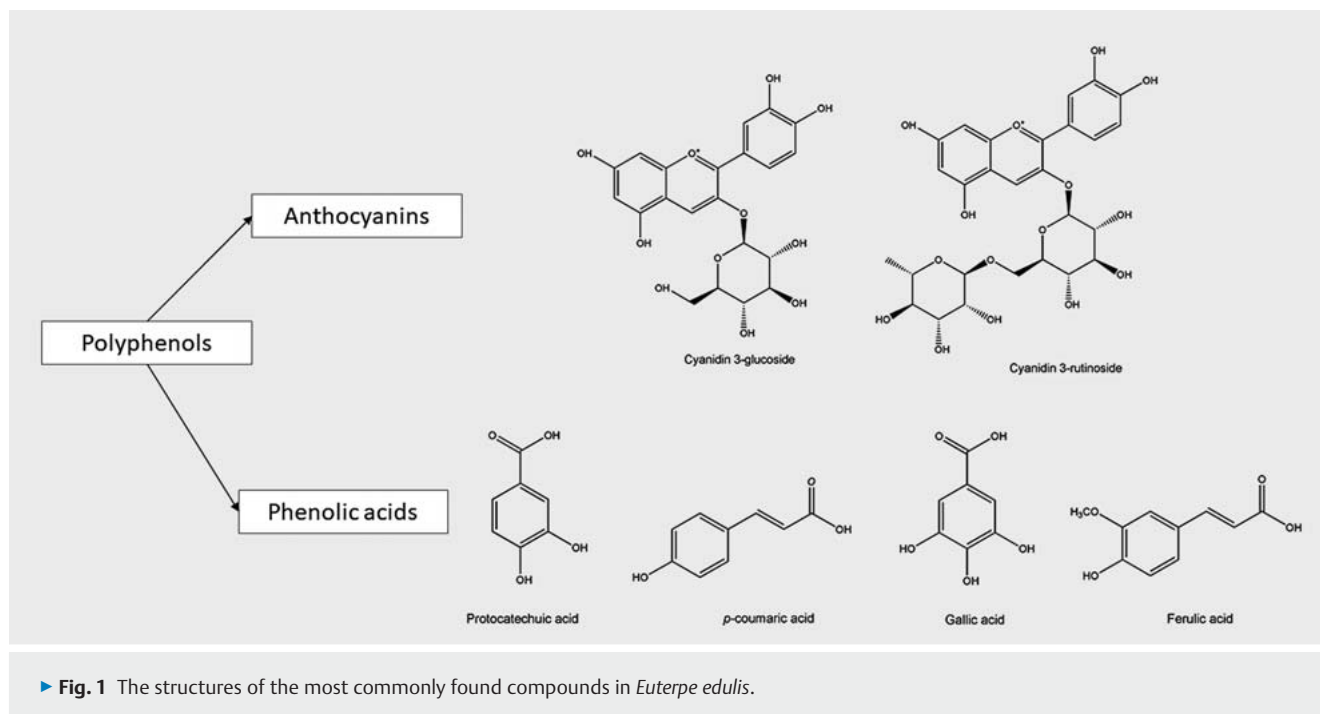
It is noteworthy that the nutritional composition and content of the bioactive compounds of juçara may suffer variations, since they are influenced by several factors: the chosen samples, place of harvest of the fruits, and differences in growing conditions of the palm trees, such as altitude, light, and fruit maturation stage [8, 9, 13, 19].

## Antioxidant Activity

The juçara fruit is considered a fruit rich in phenolic compounds. For this reason, the antioxidant effect is the most described for juçara fruits (*E. edulis*). The free radical-scavenging abilities are reported for the several studies [10, 15, 19].

The antioxidant capacity of juçara fruit extracts have been reported by several studies, the deactivation of DPPH parameter [8, 10, 16, 19, 23, 30] and FRAP [9, 11, 16, 19, 23, 30] being the most studied. The ORAC has already been used [10, 11].





► Fig. 1 The structures of the most commonly found compounds in *Euterpe edulis*.

The antioxidant capacity assessed by FRAP values are different: 1158.0  $\mu\text{mol}$  of Trolox equivalent/100 g (dwb) [9] and 2155  $\mu\text{mol}$  Trolox equivalent/100 g (dwb) [15].

Values for parameter DPPH presented great variation, as demonstrated by Bicudo, Ribani and Beta [10] (745.3  $\mu\text{mol}$  of Trolox equivalent/g on a dwb), when compared to those presented by our research group in the Cardoso et al. [15] study (2802  $\mu\text{mol}$  of Trolox equivalent/g on a dwb). The DPPH values in juçara samples are higher than the values found for açai fruit (*E. oleracea* and *E. precatória*, 133.4 and 320.3  $\mu\text{mol}$  of Trolox equivalent/g dwb, respectively) [31].

The ORAC values in juçara pulp range between 1088.10 and 2071.55  $\mu\text{mol}$  Trolox equivalent/g dwb in study performed by Bicudo et al. 2014 [10], while the ORAC values reported by Inada et al. [11] were intermediary (1544  $\mu\text{mol}$  Trolox equivalent/g dwb) in comparison than those cited [10]. Despite the fact that both studies considered freeze-dried samples, the Bicudo et al. [10] samples from southern Brazil were processed by the researchers prior to the analysis, whereas the fruits used by Inada et al. [11] from southeast Brazil were processed by a specialized company. The antioxidant capacity values of juçara fruit between studies suggests high antioxidant capacity of these fruits. However, differences in relation to the results between investigations may be attributed to growth period, growing season, location geographical, cultivar variation, sample extraction methods used, differences in the units reported, and spectrophotometric standards employed, which make a direct comparison difficult.

Despite the potential antioxidant effect already well demonstrated *in vitro*, few clinical trials evaluated oxidative stress biomarkers *in vivo*. The bioactive compounds of the berries exert important relation with the oxidative stress acting as scavengers for free radicals. Oxidative stress happens due to the imbalance be-

tween the cellular production of reactive species and the antioxidant capacity to defeat these injuries [32]. Excessive reactive oxygen species (ROS) productions are related to cell damage, necrosis, and cell apoptosis due to oxidation of protein, lipids, and DNA [33].

A recent study evaluated the bioproducts of *E. edulis* (lyophilized pulp, defatted lyophilized pulp, and oil) effects on nonalcoholic fatty liver disease induced by a high-fat diet for 4 wk. The rats were divided into standard diet, high-fat diet alone, or combined with oil, lyophilized pulp, or defatted lyophilized pulp. The groups that received pulp (defatted or not) attenuated the steatosis and lipid peroxidation in tissues, while the oil did not show the same effect. The most promising product appeared to be lyophilized pulp defatted, possibly due low lipid content and high ACNs and phenols [34]. Lipids are susceptible targets of oxidation because of their molecular structure, and their peroxidation is proposed as markers of lipid damage [35]. Further, anthocyanins are potent antioxidants which act on the attenuation of lipid peroxidation through donation of electrons or hydrogen atoms to reactive species. [36].

An investigation evaluated the combination of freeze-dried juçara pulp added to diet or in combination with moderate-intensity aerobic exercise training on hepatic oxidative stress and inflammatory markers in ApoE  $-/-$  mice [14]. Animals that received exercise showed decreased SOD activity independent of juçara intervention diet, there being an effect of exercise on SOD activity. The explanation for the decrease in SOD activity is that the liver reduced ROS generation due the exercise. It is suggested that stress oxidative reduction plays a role with decrease the requirement of protective response because of exercise training [14].

However, other experimental studies observed effect on antioxidant enzymes after intervention with juçara extract. A study

assessed the antioxidant enzymes in the livers of ApoE  $-/-$  mice with freeze-dried juçara extract intervention after selecting the best method to ACN extraction [17]. The extraction method with ethanol and citric acid resulted in the highest ACN concentration. The animals were divided into five groups: positive control – G1 (ApoE knockout, received AIN-93 M), negative control – G2 (C57BL/6, received AIN-93 M), G3, and G4 (ApoE knockout, received AIN-93 M plus 2% and 6% freeze-dried juçara extract, respectively), and G5 (ApoE knockout, received AIN-93 M plus 50 mg/kg/d of simvastatin). A significant decrease in enzymatic activities of CAT and SOD was observed in G3 and G4 when compared to the treatment pattern (positive control). Authors reported that juçara extract possibly supplied the antioxidant activity exerted by these enzymes through the action of ACNs and their metabolites.

Another study evaluated the antioxidant potential of juçara fruit intervention in dyslipidemic mice (ApoE  $-/-$ ). The groups treated with 2%, 6%, and 10% of juçara extract added to diet and a 2%  $\alpha$ -tocopherol acetate diet showed decreased CAT activity compared to the control mice (C57BL/6) with a standard diet. In addition, the group of animals that received a diet with 6% juçara extract showed smaller SOD activity as the other groups [16].

ApoE  $-/-$  mice have disabilities in a protein receptor and for this reason have elevated cholesterol levels and high susceptibility to develop atherosclerosis and hepatic steatosis [37]. These animals have been used to explore risk factors for lipid metabolism disorders and therapeutic potential of natural compounds on liver diseases. These conditions are related to the exacerbated production of reactive species [16,38,39], and therefore, dietary sources rich in phenolic compounds with antioxidant potential are of great interest, as in the case of the juçara fruit.

The recent study by Freitas et al. [40] investigated the effect of the juçara intervention during 50 d in four groups of Wistar rats: commercial diet (control), G2 (commercial diet plus *E. edulis* [4%]), G3 (commercial diet plus lyophilized pulp [10%]), and G4 (commercial diet plus lyophilized and defatted pulp [10%]). The results showed that the G3 and G4 groups decreased lipid peroxidation. In addition, the group that received defatted pulp decreased the enzymatic activity of CAT, glutathione S-transferases and SOD when compared to the other groups. The higher content of ACNs in G4 may have contributed to modulation of the redox potential.

Freitas et al. [41] investigated the antioxidant and toxic effect after juçara intervention on renal and cardiac tissues in Wistar rats fed with cafeteria diet. The main results were a significant increase in CAT activity in tissues of animals fed with cafeteria diet plus 5% of *E. edulis* lyophilized extract, plus 10% of *E. edulis* lyophilized extract and 10% *E. edulis* defatted lyophilized extract. No effect was reported on lipid peroxidation to cardiac and renal tissues after juçara intervention. The study suggests a decrease of oxidative stress levels due to the increase of enzymatic activity in cardiac tissues of animals fed with *E. edulis*. The authors hypothesized that extracts of *E. edulis* would prevent the inhibition of the expression of these enzymes, thus promoting the increase of the activity of some antioxidant enzymes.

To the best of our knowledge, the only clinical trial with humans was carried out by our research group. In a clinical trial with

juçara juice ingestion, healthy individuals had biomarkers of oxidative stress assessed before and after 1 h, 2 h, and 4 h of a single intake of 450 mL. The fruits were processed with the addition of water, and there were 33.4 g total solids of juçara in the ingested sample. Repeated measures of analysis variance revealed a significant interaction (between time and treatment) with decreased lipid peroxidation over time. Treatment had a significant effect on GPx, with a maximum activity of 2 h after acute consumption. This is the first and only evidence that has been found regarding juçara fruit ingestion by humans and showed a positive effect of juçara juice on the antioxidant status and oxidative damage of healthy subjects [15].

The results of experimental studies that evaluated the effect of intervention with juçara on antioxidant enzymes still remain controversial. Some studies have shown a decrease in the activity of antioxidant enzymes such as SOD and CAT [16, 17, 40], while other studies have reported an increase in the enzymatic activity of CAT tissue in an animal model [41] and GPx in a hemolyzed human clinical trial [15].

Exogenous antioxidants from diet can improve endogenous antioxidant activity through consolidation of defense mechanisms against excessive reactive species neutralizing free radicals or decreasing their level of activity [5,42].

According to Lei et al. [43], the antioxidant enzymes promote the passage of electrons and thus the neutralization of reactive species. Thus, the reduction of the generation of reactive species or their attenuation can be correlated with the decrease of the expression of the antioxidant enzymes. The decrease in the generation of reactive species can occur through the action of bioactive compounds present in the extracts, such as ACNs and their metabolites [44], which can reach the tissues and affect endogenous antioxidant potential.

However, it is proposed that by indirect pathways ACNs could stimulate endogenous antioxidant defense by some mechanisms such as activating genes that encode enzymes [45], repairing and stimulating the activity of the antioxidant enzymes SOD and GPx, and so improving the glutathione [46]. Considering clinical trials and effect of ACN-rich fruits, in general the modulation of endogenous antioxidant enzymes remains uncertain, since some papers report an increase following intervention while others presented no significant findings [35]. Still, enzymatic antioxidant activity is influenced by several factors, such as the animal model and the type of extract used in experimental trials [16].

Considering the effect of the juçara extract on lipid peroxidation, some studies have demonstrated the attenuation of this biomarker of oxidative damage [15, 34, 40].

Lipid peroxidation is a process associated with a significant production of reactive species inside cells. These processes could cause damage of membranes, proteins, and DNA. For this reason, the decrease of free radicals production can consequently generate less injury to the cellular structures [39].

The phenolic compounds are usually related to the bioactive properties and modulation of oxidative stress biomarkers. The decrease of lipid peroxides in serum possibly happened due the absorption of juçara polyphenols, which probably acted to eliminate free radicals or scavenging peroxy radicals. For this reason, it is necessary to further research the bioavailability of the main bioac-

► **Table 2** Experimental studies investigating the effect on lipid profile after *E. edulis* supplementation.

Authors	Animal Model	Time	Concentration added in diet	HDL-C	LDL-C	Cholesterol Total	Triacylglycerol
[14]	ApoE knockout	12 wk	2%	No effect	No evaluated	No effect	No effect
[16]	ApoE knockout	75 d	2%	No effect	No effect	No effect	Decreased
			6%	Decreased	No effect	No effect	Decreased
			10%	Decreased	Decreased	No effect	Decreased
[17]	ApoE knockout	75 d	2%	No effect	Decreased	No effect	No effect
			6%	No effect	Decreased	Decreased	No effect
[18]	Without specific model	10 wk	2%	No evaluated	No evaluated	Increased	No effect
[40]	Wistar ( <i>Rattus norvegicus</i> )	4 wk	10%	No effect	No effect	Decreased	No effect
[54]	Wistar	3 wk	0.5%	No effect	No evaluated	Decreased	Decreased
[55]	Wistar	3 wk	0.5%	No effect	No evaluated	Decreased	Decreased

tive compounds present in juçara fruits and their metabolites generated during digestion and absorption in humans or *in vivo* experimental models, making possible the confirmation of the suggested human healthy-promoting effects.

## Metabolic Parameters

Several studies have related the effect of ACN-rich fruits on metabolic parameters, especially on biomarkers associated with cardiovascular protection. The cardioprotective effects of such diets are often attributed to their polyphenol content [47, 48].

Cardiovascular diseases (CVD) are the main public health problem in modern life [47]. Lipoproteins biomarkers may serve as predictor parameters to analyze risk factors or protection for CVD. High levels of LDL-C and very low-density lipoprotein are associated with a higher risk of developing CVD, while HDL-C values are considered as a protection factor [49, 50].

Berries can be related in the prevention of atherosclerosis by inhibiting lipid peroxidation and improving the antioxidant status [47, 48]. Other effects of berries are associated with reducing the cholesterol levels and so decreasing the possibility of endothelial damage and cholesterol deposition in the cells [40]. In this context, benefits on metabolic parameters, especially lipid profile, are associated with ACNs. The action of ACNs is related to a decrease in LDL-C, inhibition of lipid oxidation, and increased fecal excretion of sterol acids [51, 52].

The nutritional composition of juçara fruit is interesting, and fruits rich in ACNs are also an excellent source of unsaturated fatty acids [8, 19]. These unsaturated fatty acids are associated with health benefits by decreasing triacylglycerols and hepatic lipogenesis [53].

In recent years, the evaluation of metabolic parameters in animal experimental studies from the administration of juçara has called the attention of researchers. Some studies *in vivo* use ApoE-deficient mice due to the accelerated atherosclerosis process. In the analyzed studies, only three investigations evaluated the effect of juçara on ApoE mice [14, 16, 17]. ► **Table 2** present

results of experimental studies that investigated *E. edulis* supplementation effect on lipid profile.

In one study, a group of ApoE knockout mice that received 10% juçara extract supplementation had a significant decrease in weight compared to the groups supplemented with 2% and 6% of juçara extract and with 2%  $\alpha$ -tocopherol acetate [16]. The group that received 10% of juçara extract presented a decrease in non-HDL-C concentrations compared to the groups that received 2% juçara extract and 2%  $\alpha$ -tocopherol acetate supplementation. The most important effect was a decrease in the triacylglycerol concentration in groups of animals that received juçara extract (2%, 6%, and 10%) supplementation, which is a fact that could be involved in the attenuation of hepatic steatosis [16].

An experimental model study with pregnant rats reported juçara's effect on the lipid profile, glucose, and inflammatory markers during pregnancy and lactation [54]. The groups that received juçara freeze-dried powder for 21 d (control diet with 0.5% of juçara added [C]) and diet enriched with hydrogenated vegetable fat with 0.5% of juçara [T]) decreased the TC and triglycerides concentrations compared to the group that only received a hydrogenated vegetable fat diet. A recent study which used a very similar protocol to that of the study by Morais et al. [54] reported decreases in weight gain and triglycerides in offspring whose mothers were fed diets with 0.5% juçara freeze-dried powder during pregnancy and lactation.

In the other investigation (more details of which can be found in the Antioxidant Activity section), the groups that received the standard diet AIN-93 M supplemented with 2% and 6% of freeze-dried juçara, or a standardized diet AIN-93 M plus 50 mg/kg/d of simvastatin, showed a significant reduction in glucose, LDL-C, and ratios of TC/HDL-C and LDL-C/HDL-C compared to the treatment pattern (positive control). The animals that received juçara extract (2% and 6%) showed lower values of TC, showing good results on the reduction of cardiovascular risk [17].

A study presented the juçara supplementation effect of 10 wk on metabolic parameters in rats subjected to high fat and high calorie diets. The main result was that the groups that received



0.5% of juçara improved their glycemic response. The animals that received hypercaloric and hyperlipidemic diets in conjunction with 0.5% and 2% of juçara did not present changes in body composition. Unexpectedly, animals that received normocaloric diet with addition of 2% juçara gained body mass. Adiponectin values of the group with 0.5% of juçara supplementation decreased compared to the control group [18].

A recent study [40] reported that groups of Wistar rats that receive lyophilized and defatted pulp of juçara (10%) decreased serum levels of TC, while other parameters such as glucose, triglycerides, HDL-C, AST, and ALT did not show any significant differences between the groups. The results presented by Castro et al. [14] are in agreement with other studies [18,40], reporting no effect of the intervention on lipid profile in an experimental animal trial.

The different animal models and concentrations of juçara in experimental studies make difficult to compare the investigations. Some investigations reported weight loss [16,55], decreased triglycerides [16,54,55], reduction of LDL-C [16,17], and decreased of TC [17,40,54], while other animal investigations have reported no effect on the lipid profile [14,18,40]. Despite the cardioprotective effect of berries being widely studied due to their content of bioactive compounds and ACNs, the effects of juçara intervention on lipid profile still seem inconclusive. For this reason, further studies are encouraged.

Considering juçara's effect on the blood glucose, a study carried out by Oyama et al. [18] had as a main result the improvement of glycemic response in mice fed with normocaloric, hypercaloric, or hyperlipidemic diet added with 0.5% of juçara freeze-dried powder concentration. In the same way, the study by Argentato et al. [55] was also effective in decreasing blood glucose after the addition of 0.5% juçara freeze-dried powder concentration in the offspring during their maternal diet. Other studies reported a significant decrease in blood glucose after 2% and 6% of juçara freeze-dried extract in the diet of ApoE knockout mice compared to the control group [17].

There is evidence that phenolic compounds may promote glucose homeostasis through the stimulation of type 4 glucose transporters. In addition, ACNs can activate protein kinase by adenosine monophosphate, which acts on the uptake of glucose by tissues promoting lipolysis and reduction of cholesterol synthesis [56].

Evidence presented by experimental studies in animals seems promising; however, there is a concern that there is not a long-term clinical trial in humans to better clarify the effects of juçara pulp or juice intake on metabolic parameters affecting the prevention or treatment of chronic diseases. Animal studies are important for assessing potential biological activities but should be interpreted with caution because of these models' limitations.

In addition, randomized controlled trials are the most reliable investigations to infer cause and effect relationships. In order to establish interactions between phenolic compounds and clinical outcomes, controlled interventions are necessary [48].

It is noteworthy to mention that, despite the possible health benefits of juçara fruit for metabolic rates/biomarkers, standardizing strategies for obtaining more exact conclusions still deems necessary to more accurately verify the influence of juçara inter-

vention as preventative or complementary treatment for chronic illnesses. These are concentration levels of juçara extract used in diets, whether it is used as juice, pulp, or freeze-dried powder; the time of consumption of participants, and laboratory biomarkers.

It is necessary to consider the differences between the bioavailability of phenolic compounds between animals and humans [48]. In this way, the most effective method of assessing the actual effect of polyphenol-rich interventions in humans, especially on cardioprotection, would be through controlled and randomized controlled trials appropriately powered [48].

More attempts and efforts should be directed to elucidate the mechanisms related to the effects of juçara fruits through *in vivo* models, considering metabolites of phenolic compounds at biological concentrations.

### Anti-Inflammatory Effect

Inflammation is a process of the immune system characterized as a response to some injury. Cytokines are immune-modulatory molecules that are used as markers to assist the quantification of the inflammatory response [57].

NF- $\kappa$ B is a transcription factor that when activated stimulates the expression of genes responsible for the production of cytokines. Pro-inflammatory biomarkers include acute phase proteins, cytokines (TNF- $\alpha$ , IL-6, IL-1 $\beta$ , monocyte chemoattractant protein 1), and adhesion molecules (E-selectin, P-selectin, soluble vascular cell adhesion molecule-1, soluble intercellular adhesion molecule-1). Anti-inflammatory markers can be evaluated by cytokines such as IL-10 and adiponectin [57]. In addition, gene expression of transcription factors and receptors in immune cells should be stimulated or inhibited being also considered biomarkers of the inflammatory state [57].

The inflammatory response may influence reactive oxygen species production and thus redox status. This cycle favors the environment of oxidative stress and inflammatory status, causing health damage and promoting the development of chronic diseases [57].

In this context, the phenolic compounds could confer protection against chronic diseases related to inflammation [57]. Polyphenols may act to activate or inhibit various signaling pathways by modulating proteins, resulting in the activation of transcription factors (for example, NF erythroid 2-related factor 2, NF- $\kappa$ B, changing receptor activation as well as its ligands as proliferator-activated receptor  $\gamma$  [58].

The subclass of polyphenols, with significant quantities in the juçara fruit, are ACNs. It is suggested that important biological activities of berries are related to ACNs, such as anti-inflammatory effect [57,59]. The ACN's action on inflammatory state can occur through the control of cells migration and proliferation, as well as by inhibiting the production of inflammatory mediators [57,59,60].

Finding dietary strategies that perform on the inflammatory state have important implications for reducing the risk of chronic diseases and may help to update guidelines with target of promoting health [57].

Some experimental animal studies have evaluated the juçara supplementation effect on inflammatory markers. In the study re-

ported by Freitas et al. [40] (more details of it can be found in the Antioxidant Activity section), the G4 (10% of juçara lyophilized and defatted extract added in the diet of Wistar rats for 50 d) had lower expression of pro-inflammatory cytokines tissue (IL-17, IFN- $\gamma$ , and TNF- $\alpha$ ) compared to the other groups (oil and only lyophilized pulp). However, the G4 was also associated with decreased anti-inflammatory biomarkers (IL-4 and IL-10) compared to the other treatments. A decrease in pro-inflammatory cytokines production can generate a reduction in anti-inflammatory mediators contributing to maintain tissue homeostasis [61]. The juçara supplementation was considered a promising alternative to modulate the inflammatory response.

A study [55] supplemented juçara (0.5%) in control diet and diet enriched with hydrogenated vegetable oil (with high content of trans fatty acids) on maternal diet during pregnancy and lactation in Wistar rats. The results showed that diets with a high content of trans fatty acids increased inflammatory markers (TNF- $\alpha$  and TNFRI), which was expected, whereas the groups receiving juçara increased the anti-inflammatory marker IL-10 concentration in the brown adipose tissue.

The study carried out by Morais et al. [54] (more details in the Metabolic Parameters section) reported that the groups of (pregnant or lactating) rats that received diet with 0.5% juçara (CJ and TJ) decreased pro-inflammatory cytokines IL-6 and TNF- $\alpha$  and gene expression of IL-6R, TNF- $\alpha$ , and toll-like receptor-4. In contrast, the cytokine anti-inflammatory IL-10 and IL-10/TNF- $\alpha$  ratio was higher in the CJ group than in the T group. The authors believe that the anti-inflammatory effect of juçara may be associated to the polyphenols content, particularly ACNs and polyunsaturated fatty acids.

Morais et al. [62] observed an experimental animal study that supplementation with 0.5% juçara in diet with hydrogenated vegetable fats (diet rich in trans fatty acids) decreased NF- $\kappa$ B pathway activation and TNF- $\alpha$  receptor I in the liver of rats. Possibly, these effects contributed to the decrease of the pro-inflammatory markers IL-6 and TNF- $\alpha$  expression in the liver and the retroperitoneal white adipose tissue. In addition, the groups that received intervention with 0.5% of juçara increased anti-inflammatory markers such as IL-10 and IL-10/TNF- $\alpha$  ratio in the offspring's liver compared to the group that received just diet enriched with hydrogenated vegetable fats. The phenolic content in maternal diet had a protective effect against the inflammation status.

An experimental study reported that an intake of 2% of juçara freeze-dried powder in hypercaloric and hyperlipidic diet of mice promotes a reduction of IL-10 in epididymal adipose tissue and IL-6 in mesenteric adipose tissue, this way decreasing the inflammation. However, the 0.5% juçara concentration was not able to change this process [18].

A study carried out by Castro et al. [14] reported a 42% decreased in monocyte chemotactic protein-mRNA 1 expression (marker related with the atherogenic process) was found in the liver of ApoE knockout mice exposed to the exercise training only. The juçara supplementation showed no effect on this marker.

Juçara seems to affect inflammatory status in favorable ways in experimental animal studies. Most of the studies analyzed showed a decrease in the pro-inflammatory markers after supplementation with juçara, particularly the markers TNF- $\alpha$  [40, 54, 62] and

IL-6 [18, 54, 62]. However, some investigations have reported a decrease in anti-inflammatory markers like the mediator IL-10 [18, 40], while others showed an increase in the same mediator [54, 55, 62].

Nevertheless, due to the diversity of animal models, concentrations of juçara and variety of biomarkers it is difficult to infer more specific conclusions regarding the evaluated parameters.

Although berries are related to the improvement of the inflammatory state in humans [57], controlled clinical trials that evaluate the effect of juçara fruit, juice, or pulp on inflammatory parameters in humans are still lacking.

To better understand the relation between juçara fruit and modulation of inflammatory state, it is imminent that studies evaluating inflammation include not only isolated parameters, but a range of inflammatory biomarkers. For this reason, clinical trials should be encouraged.

The beneficial of the studies that evaluated the juçara effect on the inflammation biomarkers related their effects with the phenolic compounds content, particularly ACNs. However, it is important to highlight that the modulation of the intestinal microbiota is considered a mechanism by which ACNs can exert their benefits [63]. It is suggested that the downregulation of pro-inflammatory markers can occur through the modulation of the microbiota by the ACNs and their metabolites [54]. In this way, more studies in this area are needed.

## Other Effects

Morais et al. [62] has shown that the addition 0.5% of juçara in maternal diet (TJ group) restored the fecal content of *Bifidobacterium* spp. and increased colonic zonules occludentes (ZO-1) mRNA expression. The ZO-1 are membrane proteins that regulate cellular permeability and play role in tight junctions acting as a cellular barrier [64]. Thus, alterations in the expression of the ZO-1 mRNA expression protein may change the tight junction barrier improving intestinal permeability [65]. The authors hypothesize that the increase in *Bifidobacterium* spp. in juçara groups play role with the decrease of pro-inflammatory markers (shown in the Anti-Inflammatory section). This effect may also be related with decreased permeability of the intestinal mucosa due to increased ZO-1 expression. The authors associate the modulation of the intestinal microbiota with the metabolites of the juçara compounds by gastrointestinal tract.

The investigation performed by Morais et al. [54] also showed an increase in probiotic organisms (*Lactobacillus* spp.) in the colon of offspring whose mothers were fed with 0.5% of juçara. This fact acts with the downregulation of pro-inflammatory cytokines and the increase of anti-inflammatory mediators. The authors believe that the modulation of intestinal microbiota by the compounds present in the fruit juçara (fibers and polyphenols) promote the improvement of the inflammatory state, reducing the risk of developing chronic diseases.

Still on this path, the intestinal microbiota in anaerobic culture *in vitro* was modulated by juçara pulp. There was a significant increase in the population of bifidobacteria (beneficial bacteria) after 24 h of fermentation compared to the placebo group (negative control: basal nutrient without substrate and with prebiotic effect added). Most ACNs were degraded during digestion, but

46% of the total phenolic compounds resisted digestion, making them important sources of antioxidant activity that can reach the colon. This is the first study to assess the possible effects of probiotic from juçara pulp. The researchers note that studies in humans should be encouraged to further prove the effectiveness of this pulp [26].

It is important to note that Felzenszwalb et al. [66] evaluated the toxicological effect of juçara pulp and observed that not adverse effects were reported on human healthy may be the ingredient a lot of food. Recently, juçara has also called attention in the development of new products. Geraldi et al. [67] added juçara pulp and commercial probiotic (*Lactobacillus acidophilus*) in yogurts to evaluate the survival probiotic in storage and after gastric and enteric digestion *in vitro*. Juçara pulp seems to be a good strategy in the production of yogurts increasing the resistance of probiotics until 14 d of storage even after the stimulation of gastrointestinal conditions. It is suggested with this study that polyphenols, in particular ACNs, may have improved the probiotic viability.

The study by Argentato et al. [55] also evaluated the supplementation of juçara (0.5%) in maternal diets enriched with hydrogenated vegetable oil (with high content of trans fatty acids) on energy expenditure biomarker. The juçara intervention (0.5%) increased the UCP-1 expression in brown adipose tissue, a parameter related with energy expenditure through thermogenesis. The authors attribute the results to bioactive compounds of juçara and believe that this fruit can be used to prevent obesity. However, the mechanisms by which phenolic compounds can affect thermogenesis are not yet totally understood. In addition, the composition of juçara fruits, rich in oleic and palmitic fatty acids, added still in a lipid-rich diet, could have also influenced the increase of UCP-1 expression.

There seems to be an emerging interest in relating juçara fruit to its effect on probiotics. Juçara fruit caused an increase of mRNA expression on ZO-1 and in probiotic populations (*Bifidobacterium* and *Lactobacillus* spp.). When added to dairy products, juçara fruit also provided probiotics with resistance even after being exposed to gastrointestinal conditions. In general, the authors relate the positive findings to the nutritional composition of juçara fruits rich in ACNs and unsaturated fatty acids. These results appear promising and could represent something in preventing chronic diseases. However, it is worth mentioning that the modulation of the intestinal microbiota by juçara fruit in humans has not yet been demonstrated.

## Conclusions

Disease prevention has gained relevance in modern society. Food sources of natural and bioactive compounds can influence and help healthy bodies. It is necessary to support research to discover further new findings that confirm the biological effects of foods and beverages. It is important to consider that some foods can exert influence over the prevention of many chronic diseases by maintaining a healthy body.

The purpose of this review was critically to evaluate the existence of clinical data about juçara fruit and the biological effects. Data reviewed considered juçara, juice and freeze-dried juçara

pulp *in vivo* and *in vitro* trials. A chapter about the nutritional characterization of juçara fruits was also included in order to help the understanding of its biological effects.

It is suggested that juçara supplementation may have positive effects on lipid peroxidation, modulation of the inflammatory state, improvement of blood glucose levels, and a possible beneficial effect on probiotic microorganisms. The fruit's effect on lipid profile parameters and antioxidant enzymes still seem to be a bit controversial when some studies show positive effects and others do not.

Most *in vivo* studies that analyze the biological effects of juçara fruit are performed on animal models. Although results seem promising, it is necessary to standardize important strategies such as concentration levels of prepared fruits, whether juice, pulp, or freeze-dried powder is used, and the time of consumption.

The positive results found after juçara administration are attributed to its interesting nutritional composition. Components of the juçara fruit such as phenolic compounds, especially ACNs and unsaturated fatty acids, are suggested as being responsible for these effects.

It is important to emphasize that phenolic compounds are metabolized by gut microbiota, and their metabolites can exert effects on gut permeability and contribute to the biological effects of the parent compounds. The bioavailability and metabolism of polyphenols may be different between animals and humans. In this way, there is a lack of clinical trial in humans to better clarify the effects of juçara pulp, or juice intake on human biology, affecting the prevention or treatment of chronic diseases.

As already mentioned, it is possible that sometimes juçara is named açaí to make it commercially relevant, despite belonging to a different species of palm [7]. With this present review, it is hoped that the potentially health benefit of juçara fruit and its derivatives have grown in importance concerning the human nutrition and strengthening its identity.

In addition, the palm tree *E. edulis* is an important palm for fauna and flora to the Atlantic Forest. Therefore, further knowledge about its main biological effects may promote the conservation of the species of palm, which is at risk of extinction nowadays.

## Supporting Information

A flow chart of the selection of studies is available as Supporting Information (Fig. 1S).

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## Conflict of Interest

The authors declare no conflicts of interest.

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