European Journal of Nutrition & Food Safety

12(10): 134-145, 2020; Article no.EJNFS.62279
ISSN: 2347-5641

Gamma Radiation Applied in *Euterpe oleraceae* Pulps

Lucia Maria Jaeger de Carvalho[1*], Bruno Paranhos[1], Edgar Francisco Oliveira de Jesus[2] and José Luiz Viana de Carvalho[3]

[1]Rio de Janeiro Federal University, Laboratory of Technology and Instrumental Analysis, Faculty of Pharmacy, Rio de Janeiro, Brazil.
[2]Rio de Janeiro Federal University Laboratory of Nuclear Instrumentation – COPPE, Rio de Janeiro, Brazil.
[3]Embrapa Food Technology, Rio de Janeiro, Brazil.

Authors' contributions

This work was carried out in collaboration among all authors. Author LMJC elaborated (wrote protocols and wrote the first draft of the manuscript) and coordinated the Project. Author BP managed the literature searches and executed the analyses. Author EFOJ carried out the samples irradiation. Author JLVC participated in the literature searches and colaborated in the first draft of the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/EJNFS/2020/v12i1030310
Editor(s):
(1) Dr. Michael Lokuruka, Karatina University, Kenya.
Reviewers:
(1) Dominic Augustine, Ramaiah University of Applied Sciences, India.
(2) S. Sudheshna Babu, Acharya Nagarjuna University, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/62279

Original Research Article

Received 25 August 2020
Accepted 31 October 2020
Published 28 November 2020

ABSTRACT

Aims: The aim of this work was to evaluate the optimal radiation dose to maintain the antioxidant capacity of conventional and organic acaí freeze-dried pulps.
Study Design: All analyses were conducted in sextuplicate for each experiment.
Place and Duration of Study: Were conducted at the LATAIA and the irradiation processes at the Laboratory of Nuclear Instrumentation, UFRJ, Rio de Janeiro, Brazil. The study was carried out from July, 2018 to March, 2020.
Methodology: Frozen acaí pulps from two commercial brands, one of them organic and other conventional were used and purchased in the city of Rio de Janeiro, packed in plastic bags containing 1 kg. For each brand, frozen pulps (5 kg) were thawed at 4ºC, opened and homogenized. Samples were subdivided into aliquots ranging from 20 to 300 g for the assays and

**Corresponding author: Email: luciajaeger@gmail.com;*

frozen inside the plastic bags until analyses. A Cobalt 60, Gammacell irradiator was used and doses of 1.25. 2.5. 3.75 and 5 kGy were applied in the in natura pulps. Antioxidant capacity was performed by the ORAC and DPPH methods and, phenolic compounds by Folin Ciocalteau method and, total anthocyanins and majority anthocyanidins by HPLC.

Results: Anthocyanins increases at irradiaton dose up to 3.75 kGy in organic açaí but it was not significant in conventional acaí irradiated at low doses (1.25 to 3.75 kGy). Our results suggested that irradiation doses up to 5 kGy do not decrease total phenolic or anthocyanin contents nor the pulp antioxidant activity compared with non-irradiated pulps. The results showed irradiation did not reduce these analytes, and even increased in the organic acaí.

Conclusion: The study evidenced that gamma irradiation can be an alternative safe process for fruit pulps preservation. We conclude that irradiation doses up to 5 kGy can be used in acaí without harming its antioxidant properties.

Keywords: Gamma radiation; cobalt 60; acaí; Euterpe oleraceae.

1. INTRODUCTION

The açaizeiro (*Euterpe oleracea* Mart.) is the most productive palm in the Amazon rainforest, which also stands out for the economic potential of its products such as palm hearts and pulp extracted from the fruit. Brazil is its largest producer, consumer, and exporter, with the state of Pará responsible for 95% of national production [1,2]. The fruits are used in the production of acaí pulp, a food widely consumed in the North region and, with increasing demand in the national and international market [2,3,4]. According to the State of Pará Government, in 2007, 60% of the US $ 17 million revenue from exports of fruit juices and pulps from the state of Pará was generated by acaí [5]. The wide acceptance of the fruit in the production of drinks, sweets, jellies and supplements is growing and, arouses great interest from investors and researchers on the raw material [4]. Acaí pulp is an important source of lipids, proteins, fibers, minerals (Mn, Cu, Cr, B), and vitamins (Vit E –α-tocopherol), being quite attractive to the food industry as natural high-calorie food [6].

Additionally, because of its high anthocyanin content specially the majority ones like cyanidin-3-o-glycoside and cyanidin-3-o-rutinoside, as well as other phenolic compounds with antioxidant capacity, it is considered a nutraceutical food [2,7,8,9,10]. Anthocyanins have pharmacological and medicinal properties as anticarcinogenic, anti-inflammatory, antimicrobial, helping to prevent cardiovascular, circulatory and neurological diseases and preventing oxidation of low-density lipoproteins [2,11]. Because acaí pulp is a highly perishable product (12 hours, under refrigeration), it is necessary to use a combination of preservation strategies to increase its shelf life. Pasteurization and freezing are the main preservation methods used in acaí pulp for exportation, even though they affect nutritional and sensory attributes [1,2,5]. These changes result in oxidation reactions, decreased anthocyanin content, and depigmentation (discoloration) of the pulp, which may be of microbial, enzymatic, or chemical nature. In order to extend the shelf life while preserving the original characteristics of the pulp as much as possible, other preservation methods have been studied, such as freeze-drying, obstacle/barrier technology, high hydrostatic pressure, dehydration, and irradiation. From the above-described methods, freeze-drying and irradiation may cause negligible changes in flavour and loss of nutritional components, when correctly applied [2,3,12].

In optimal doses, ionizing radiation can destroy pathogenic and deteriorating microorganisms in food, eliminate insects and parasites, delay the maturation and senescence of fruits and vegetables, the germinative process of plant food products [13,14]. The undesirable effects on odour and taste can be minimized by reducing the temperature during the application of radiation, minimizing the generation and dispersion of free radicals. The factor probably responsible for the smell of the raw material or irradiated food and for the oxidation of the lipids is water radiolysis. Food irradiation exposes the product to ionizing radiation such as gamma rays, emitted by radioactive isotopes of *Cobalt* 60 and *Cesium* 137, or to high-energy electrons and, X-rays. High doses of irradiation (above 10 KGy) are destined for food sterilization, medium doses (1 to 10 KGy), to increase the shelf life promoting a pasteurization effect and low doses (< 1 KGy), to decrease the senescence process of fruits, the sprouting of vegetables and, infestation by parasites and insects [15].

The present study evaluated the effects of irradiation with Cobalt 60 regarding phenolic compounds, total anthocyanins, anthocyanidins and antioxidant capacity in lyophilized organic and conventional acaí pulps.

2. METHODOLOGY

2.1 Raw Material

Frozen acaí pulps (with 14% total solids content) from two commercial brands, one of them organic and one conventional were purchased in the city of Rio de Janeiro, packed in plastic bags containing 1 kg. For each brand, the frozen pulps (5 kg) were thawed at 4ºC, opened and homogenized. Samples were subdivided into aliquots ranging from 20 to 300 g for the different assays and, frozen inside the plastic until analyses.

2.2 Irradiation Conditions

The samples were irradiated in a Cobalt 60 (Co_{60}) from Gammacell in the Laboratory of Nuclear Instrumentation from Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia (COPPE/UFRJ) using doses of 1.25, 2.5, 3.75 and 5 kGy, respectively, at a rate of 0,56 kGy/h. Non-irradiated samples were used as controls. All irradiations were carried out in triplicate and, maintained frozen using liquid nitrogen. These doses are in accordance with the Brazilian legislation. A scheme of the experiments in the present work is shown in Fig. 1.

2.3 Extracts of Acaí Pulps

Samples were lyophilized, weighted (1.000 ± 0.005 g) and extracted using a modified method based on Da Silva Campelo Borges et al. (2011) and Schulz et al. 2015) [8,10]. Briefly, samples were defatted using five consecutive extractions with 10 ml hexane containing 0.05 (w/v) BHT for 10 minutes inside an ultrasonic bath, centrifuged for 5 min at 15,000 g, and filtered. After the last defatting step, hexane was let to evaporate for 30 minutes at room temperature. The samples were then extracted with 4 ml of acetone-water-acetic acid (AWA, 70:29.5:0.5) for 10 minutes inside an ultrasonic bath, centrifugated, filtered, and this extraction was repeated four times. After partitioning the extracts in AWA with equal volumes of chloroform to remove carotenoids and chlorophylls, the upper phase was collected and brought to 25 ml with deionized water [9,15,16]. For the analysis of majority anthocyanidins carried out by HPLC, the samples were extracted using 2 ml of 90% methanol and 10% formic acid for 10 minutes inside, and ultrasonic bath after 1 min of vortexing. Samples were, then centrifuged and, the extraction repeated until the extract was colorless. The pooled samples were brought to 10 mL and centrifuged to remove particles before chromatographic analysis [17].

2.4 Total Anthocyanins and Anthocyanidins

The total anthocyanins in the AWA extracts was analyzed by spectrophotometry using the Giusti & Wrolstad (2001) method, and the results were expressed as cyanidin-3-o-glucoside using the following formula:

Monomeric anthocyanin pigment (mg/liter) = $(A \times MW \times DF \times 25)/(\varepsilon \times 1)$.

Where

A is the absorbance = (A510 - A700) pH 1.0 - (A510 - A700) pH 4.5;

MW is the molecular weight of cyanidin-3-o-glucoside (449.2 g. mol^{-1});

FD is the dilution factor used (10 times);

The extinction coefficient ($L.cm^{-1}.mol^{-1}$) = 26.900 and,

l the optical path (1 cm).

Anthocyanidins (cyanidin-3-o-glucoside and cyanidine3-o-rutinoside) were analyzed in a Waters® Alliance 2690-5 HPLC with Photodiode Array Detector (Waters® 2996) and Empower software with a Symmetry® C_{18} Column (150 mm × 4.6; 3.5 µm). Chromatographic parameters were: Column temperature 30°C; flow: 1.0 $mL.min^{-1}$; injection volume: 50 µL; analysis time of 45 min having as mobile phase: 10% formic acid in water (solvent A) and methanol (solvent B) [17].

2.5 Total Phenolic Compounds

Total phenolics contents were quantified in triplicate by a spectrophotometric method using *Folin-Ciocalteau* reagent. Freshly prepared gallic acid standards at concentrations of 20, 40, 60, 80, 100, 150 and 200 mg. L^{-1} were used to

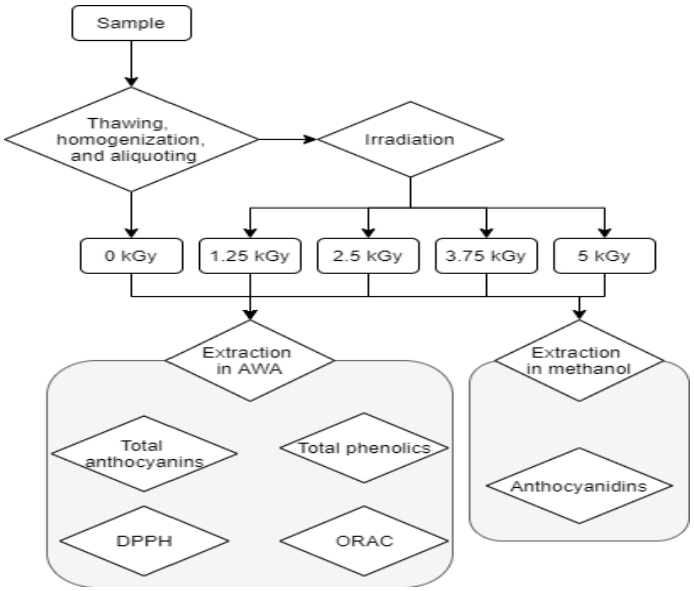

Fig. 1. Scheme indicating sample handling, irradiation, extraction and the experiments

obtain a standard curve. The AWA extracts were diluted five times with deionized water as well as a blank containing only AWA. A total of 2.75 mL of 3% *Folin-Ciocalteu* solution was added to test tubes containing 0.25 mL of each sample, blank or standard. After a slight agitation, 0.25 mL of 10% sodium carbonate solution was added, and the tubes were kept for 60 minutes in the dark. Each replicate was, then read at 765 nm on a Thermo Scientific Evolution 60 spectrophotometer. Results were expressed as mg gallic acid equivalents (mg GAE. g^{-1}).

2.6 DPPH Radical Scavenging Assay

The method described by da Silva Campelo Borges et al., 2011 and Garzón et al. 2017 [8,18] was used to determine the kinetic parameter, according to Cheng, Moore, Yu, [19]. In brief, the AWA extracts were serially diluted in methanol and, DPPH was added at a final concentration of 0.1 mM. Trolox was used to generating a standard curve, and each dilution was read, in triplicate, alongside its blank every minute for a total of 60 minutes. Antioxidant activity was calculated as EC_{50} and as RDSC (Radical Scavenging Capacity).

2.7 Oxygen Radical Absorbance Capacity (ORAC)

ORAC values were measured using a microplate reader (SpectraMax M3, Molecular Devices) [20,21,22]. Each well contained 4 nM fluorescein as a fluorescent probe and 25 µL of AWA extracts or Trolox standards (50-3,125 µM) diluted in phosphate-buffered saline (PBS). Water was added to the external wells, and after 15 minutes at 37ºC, 100 mM 2,2'- azinobis (2-methylpropionamidine) dihydrochloride (AAPH) was used to start the reaction. The wells were read every minute for a total of 90 minutes (485 nm excitation and 520 nm emission), and the ORAC value of each sample was expressed as µmol TE g^{-1} acaí dry weight.

2.8 Statistical Analysis

Results were analyzed in GraphPad Prism 7 and expressed as mean ± SD (n=3). Samples were compared using T-test and ANOVA, and comparisons with $p < 0.05$ were considered statistically significant. Groups showing $p < 0.05$ in ANOVA were also compared using the Tukey HSD test.

3. RESULTS AND DISCUSSION

3.1 Total Anthocyanins and Anthocyanidins

Table 1 shows the anthocyanins content in acaí at different irradiation doses. A slight, but not significant increase in total anthocyanins concentration was observed in conventional acaí irradiated at low doses (1.25 to 3.75 kGy) while the highest dose of 5 kGy induced a decrease in anthocyanin content. Organic acaí withstood

higher irradiation doses, showing significant increases in anthocyanin values up to 3.75 kGy, where a *plateau* seemed to be reached. Although the organic pulp had higher anthocyanin content (Fig. 2., A), this difference alone cannot explain the different behavior between the brands.

Total anthocyanins contents observed in *Euterpe oleracea* pulps in many studies largely differ according with the pulps. Coutinho et al., 2017 [23] and Fernandes et al. [24] found lower values of total anthocyanins ranging from 12.5 to 24.98 and, 36.38 mg. 100 g $^{-1}$, respectively. On the other hand, higher values reported ranging to 62.58 to 135.15 mg 100 g^{-1}; 111 mg. 100 g^{-1} [25,26,27]. Da Silva et al., 2013 [28] evaluated frozen juçara (*Euterpe edulis*) pulps irradiated at doses of 2.5; 5.0; 7.5 and, 10 KGy after 28 days stored under refrigeration at 6.9°C. The results showed similar behaviour at radiation dose of 2.5 KGy. Up to 5 Kgy a decrease in the anthocyanin contents were observed.

Pacheco-Palencia et al. [29] found contents of total anthocyanins of 205.6 mg. 100 g^{-1}. In our study values of 2.828 for the conventional pulps and the highest of 3.432 mg. g $^{-1}$ for organic ones were found. Significantly higher than others authors.

On the other hand, the effects of the irradiation in different raw materials are reported by many authors. In the present study our results are in accordance with Ayed, Yu, and Lacroix, [30], which reported that anthocyanin contents in grape juices increased with irradiation doses up to 6 kGy. Alighourchi et al. [31] evaluating pomegranate juice, observed similar results, and doses above 3.5 kGy provoked deleterious effects in anthocyanin content. The reason for these effects might be explained in the works of Kyung et al. [32] and Abad et al. [33] who demonstrated that irradiation leads to cleavage of the glycosidic bonds increasing the concentration of low molecular weight sugars. Additional evidence was found in Pradesh et al. [34] and Sagar and Kumar, [35] while evaluating irradiated soybeans, observed that irradiation leads to the release of polyphenolic compounds that could be conjugated to higher glycans. The irradiation effects on anthocyanins are different for each pigment, and diglycosides seems to be more stable than monoglycosides. The increases observed with low doses of gamma irradiation may be credited to better extraction of pigments bound to cell walls [36]. Ours results in acaí pulps are in accordance with the literature and seem to decrease after the mean threshold of 3.75 kGy.

Castelucci, [37] evaluated the bioactive compounds of native fruits after irradiation with Co_{60} at 2, 4 and 6 KGy doses. The grumixama (*Eugenia brasiliensis*) and the cereja do rio grande (*Eugenia involucrata*) presented the highest anthocyanin values among the fruits evaluated. The grumixama anthocyanins pasteurized samples presented 106.01 mg eq. cianidin-3-glucoside L^{-1} highest than the control samples (59.75) and the values of anthocyanins in the irradiated samples were 52.93; 32.36 and 48.64 mg eq. cianidin-3-glucoside L^{-1} at irradiation doses of 2, 4 and 6 KGy, respectively.

Comparing with the grumixama results, the cereja do rio grande presented the same behaviour was observed. These values were 77.11 in the control and 136.33 mg eq. cyanidin-3-o-glucoside L^{-1} in the pasteurized samples. The irradiated samples (2, 4 and 6 KGy, respectively) showed similar values compared to control sample (74.91; 77.7 and 69.47 mg eq. cyanidin-3-o-glucoside L^{-1}, respectively). However, Brazilian acai had more cyanidin-3-o-glucoside and cyanidin-3-o-rutinoside (4.0 and 2.4 mg/g, respectively) than Floridian acai (0.8 and 0.5 mg/g, respectively). Thus, the two known anthocyanins account for a statistically insignificant amount of the ORAC values for these samples.

According our results the cyanidin-3-o-rutinoside was the most abundant among the conventional and organic controls and irradiated samples. At irradiation dose of 3.25 KGy the highest values were 55.6 mg. 100 g^{-1} cyanidin-3-o-rutinoside and, 35 mg. 100 g^{-1} cyanidin-3-O-glucoside. Many authors reported the occurrence of cyanidin-3-o-rutinoside higher than cyanidin-3-o-glycoside and as well as other phenolic compounds with antioxidant capacity, is considered a nutraceutical food. [2,7,8,9,10].

Cyanidin-3-o-glucoside and cyanidin-3-o-rutinoside, the most abundant cyanidins in acaí were then, analyzed by HPLC, and results are shown in Fig. 2. (C and D). The behavior of those two analytes concentration was similar to the total anthocyanin content, where low doses of gamma radiation induced its increase up to a maximum (2.5 to 3.75 kGy), which differed slightly from the spectrophotometric quantitation (Fig. 2., B). We could not explain the high anthocyanidin content in non-irradiated organic

pulp maybe by the cultivation tracts. The values found for cyanidin-3-o-glucoside and cyanidin-3-o-rutinoside in the conventional acaí pulps were lower than in the organic ones. This behavior observed was the same for the irradiated samples.

3.2 Total Phenolic Compounds

Table 2 shows the total phenolic compounds in samples. When evaluating the irradiation effects on these analytes, only the organic pulp was significantly different by ANOVA (P = 0.0006). Despite the fact that conventional pulp showed a similar increase to the one observed for anthocyanins.

Non-irradiated pulps did not differ in phenolics concentration and had similar values reported by Schaus et al. [38] and Kang et al. [9], who also used AWA as an extraction solvent evaluate acaí pulps from two states of Brazil, Minas Gerais and Pará. The highest values were found in the pulps from Minas Gerais state ranging from 301.36 to 372.43 mg AGE 100 g^{-1} [28]. The result indicates that anthocyanins suffer a greater effect from irradiation than the others phenolics, although this group also had a slight increase in content at low irradiation doses, which decreases with higher doses, an effect observed for soybeans [39,40]. The same behavior was observed using irradiation doses of 2.5 and 5.0 KGy, respectively, in juçara (*Euterpe edulis*) pulps [34]. According with Castelucci, [37] the phenolic compounds after irradiation doses of 2; 4 and 6.0 KGy decreased. The alterations on the phenolics compounds were attributed to the fact that gamma radiation modifies the levels of some enzymes in greater or lesser synthesis of phenolic compounds [39,40].

The same pattern demonstrated for anthocyanins was observed to the phenolic compounds when high values on the first assessment day with a decreasing in the subsequent period with averages tending to be constant until the end of the experiment. The samples treated with doses 7.5 and 10.0 kGy showed the higher values of PC up to 21 days of storage [41].

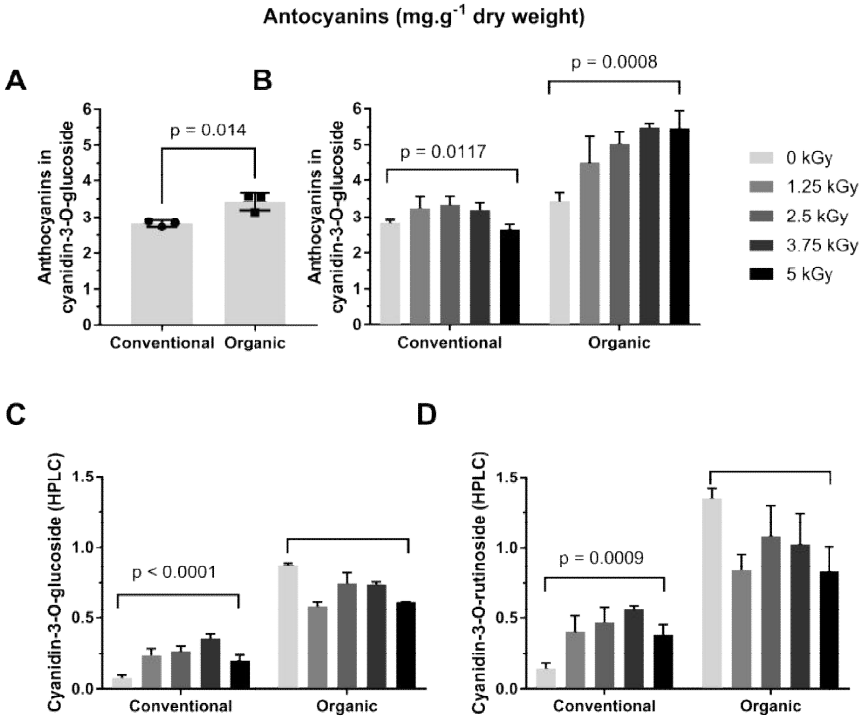

Fig. 2. Total anthocyanin content of irradiated acaí pulps. Results are expressed as ± SD (n=3) (A) Comparison between total anthocyanin content in non-irradiated conventional and organic acaí. (B) Effect of gamma irradiation in total anthocyanin content. (C) Effect of gamma irradiation in cyanidin-3-O-glucoside content. (D) Effect of gamma irradiation in cyanidin-3-O-rutinoside content

Table 1. Total anthocyanins (mg cyanidin-3-o-glucoside. g^{-1} dry weight)

Doses	Conventional acaí	Organic acaí
0 kGy	2.83 ± 0.08^{ab}	3.432 ± 0.23^{b}
1.25 kGy	3.24 ± 0.32^{ac}	4.505 ± 0.72^{ab}
2.5 kGy	3.34 ± 0.23^{ac}	5.026 ± 0.34^{a}
3.75 kGy	3.19 ± 0.21^{ab}	5.495 ± 0.11^{a}
5 kGy	2.66 ± 0.13^{b}	5.470 ± 0.47^{a}

** Results are expressed as mean ± SD (n=3). Values with different superscript letters indicate statistical significance (P < 0.05)*

3.3 Antioxidant Capacity by DPPH and ORAC

Antioxidant activity in acaí pulp extracts was measured using DPPH assay and is presented in Table 3 and Fig. 3. (A, B, C, and D) as EC_{50} and RDSC. Similar behavior was observed when comparing the results of total phenolics, which is expected since phenolics are greatly credited for their antioxidant activity. The variation in DPPH assay was only significant in the organic pulp, showing increases up to 3.75 kGy (EC_{50}) and 5 kGy (RDSC) while in the conventional pulp, the radiation dose of 5 kGy showed a decreased tendency in antioxidant activity.

The antioxidant capacity of the conventional and organic acaí pulps irradiated measured by ORAC method increased according to the radiation dose (Table 4). Once again, the differences observed in conventional pulp were not significant, and the response to irradiation was similar to DPPH.

It is assumed that those slight changes in antioxidant activity can be correlated to total phenolic content, especially anthocyanins. While the antioxidant activity in non-irradiated conventional and organic pulps was not significantly different (Fig. 3, A, C, and E), their anthocyanin content differed (Fig. 3, A), and the higher values observed in organic acaí correlate with its increase after irradiation (Fig. 3, B, C, and D). Although these effects could not be fully understood and may be an artifact due to better extraction of anthocyanins after irradiation, there were no significant deleterious effects in the pulps up to 5 kGy. A negative trend in phenolics content and antioxidant activity was observed with higher doses, and for that in this work, the doses of 2.5 kGy and 3.75 kGy were considered optimal for the preservation of acaí pulps. According with our results (8.45 and 9.92) the DPPH (EC_{50} = mg. mL^{-1}) showed similar values reported previously for acaí (*E. oleraceae*) pulp fruits (5.09; 7.26; 9.96; 11.83; 7.92 and 4.45±1.00 µmol L^{-1} Trolox g^{-1}) [22] lower than the results found in the present study. Gomes et al. [42] evaluating açaí (*E. oleraceae*) and juçara (*E. edulis*) freeze dried and spray dried samples found for juçara freeze- dried samples, EC_{50} of 3.6 and for acai 37.3, respectively. Lyophilized Brazilian and Floridian acai (*E. oleraceae*) samples werw evaluated by ORAC and for cyanidin-3-o-glucoside and cyanidin-3-o-rutinoside. The ORAC values were 750 and 730 Trolox equivalents per g (TE/g) for Floridian and Brazilian acai, respectively [22]. These ORAC values are higher than ours for conventional and organic açaí pulps but we observed that according with the increase of irradiation doses. Additionally, the DPPH results found by Castelucci, [37] are similar to our findings where the values of the antioxidant activity decreased according with the increase of the radiation doses at 2.0; 4.0 and 6.0 KGy evaluating brazilian native pulp fruits.

Bicudo et al. [43] evaluated *E. edulis* cultivated in Paraná state, Brazil, finding values of total anthocyanins ranging from 91.52–236.19 mg cyanidin-3-glucoside equivalent. 100 g^{-1}. These values are lower than ours (343.31 mg cyanidin-3-glucoside equivalent. 100 g^{-1}). The DPPH and ORAC results showed highest values than ones in the present study. Probably the highest values found by them are by the fact that the fruits were analyzed along the on-tree ripening process.

Fruits from Amazonia like “bacaba” as a new source of bioactive compounds, presented antioxidant activity and total anthocyanins (80,76 mg 100 g − 1) and ORAC values of 194,67 µM Trolox g − 1), lowest than ours findings [44].

The radiations doses used in the present work did not promote a decrease in phenolic compounds and discoloration of the total anthocyanins reported by Lee et al. [45] that observed degradation of the cyanidin-3-o-rutinoside, in specially as well as Silva et al. [46]. May be by the high doses applied promoting radiolysis.

Table 2. Total phenolic compounds (mg GAE.g^{-1} dry weight)

Dose	Conventional acaí	Organic acaí
0 kGy	21.86 ± 7.04^{a}	20.90 ± 4.32^{b}
1.25 kGy	23.49 ± 3.45^{a}	25.16 ± 6.18^{ab}
2.5 kGy	23.90 ± 4.88^{a}	28.23 ± 3.75^{a}
3.75 kGy	23.78 ± 3.70^{a}	29.78 ± 3.65^{a}
5 kGy	20.34 ± 3.76^{a}	29.14 ± 4.89^{a}

**Results are expressed as mean ± SD (n=6). Values with different superscript letters indicate statistical significance (P < 0.05)*

Table 3. DPPH - EC_{50} (g dry weight. g^{-1} DPPH) and RDSC (µmoles TE. g^{-1} dry weight)

Doses	Conventional		Organic	
	EC_{50}	RDSC	EC_{50}	RDSC
0 kGy	8.45 ± 2.00^{a}	92.63 ± 16.68^{a}	9.92 ± 0.45^{a}	80.23 ± 3.11^{c}
1.25 kGy	7.77 ± 0.30^{a}	98.73 ± 5.61^{a}	7.92 ± 1.00^{b}	91.17 ± 6.37^{b}
2.5 kGy	7.60 ± 0.41^{a}	99.10 ± 2.33^{a}	7.53 ± 0.25^{bd}	96.73 ± 2.69^{b}
3.75 kGy	7.77 ± 0.20^{a}	97.50 ± 1.58^{a}	6.34 ± 0.24^{d}	100.49 ± 2.95^{ab}
5 kG	8.46 ± 0.76^{a}	83.19 ± 6.51^{a}	6.24 ± 0.56^{d}	113.34 ± 7.87^{a}

** Results are expressed as mean ± SD (n=3). Values with different superscript letters indicate statistical significance (p < 0.05)*

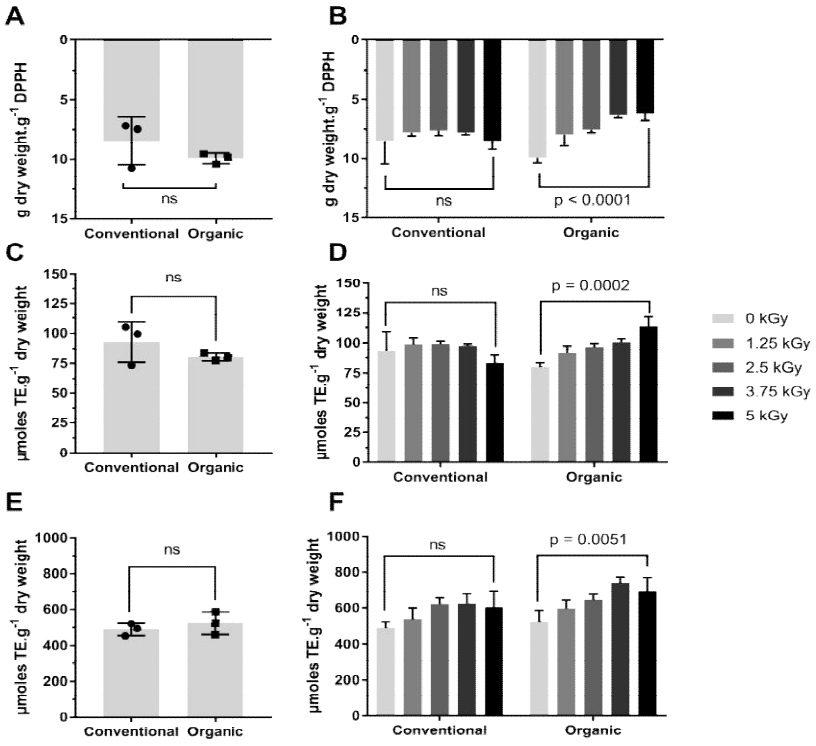

Fig. 3. Antioxidant activity of irradiated acaí pulps. Results are expressed as ± SD (n=3) (A) Comparison between DPPH radical scavenging activity as EC50 in non-irradiated conventional and organic acaí. (B) Effect of gamma irradiation in DPPH radical scavenging activity as EC50. (C) Comparison between DPPH radical scavenging activity as RDSC in non-irradiated conventional and organic acaí. (D) Effect of gamma irradiation in DPPH radical scavenging activity as RDSC in non-irradiated conventional and organic acaí. (E) Comparison between ORAC activity in non-irradiated conventional and organic acaí. (F) Effect of gamma irradiation in ORAC activity in non-irradiated conventional and organic acaí

Table 4. Antioxidant capacity by ORAC (μmoles TE. g^{-1} dry weight)

Doses	Conventional	Organic
0 kGy	491 ± 34[a]	525 ± 62[c]
1.25 kGy	538 ± 62[a]	597 ± 46[bc]
2.5 kGy	621 ± 37[a]	646 ± 32[abc]
3.75 kGy	624 ± 55[a]	743 ± 31[a]
5 kGy	604 ± 93[a]	691 ± 81[ab]

**Results are expressed as mean ± SD (n=3). Values with different superscript letters indicate statistical significance (P < .05)*

4. CONCLUSION

In this work, we evaluated the effects of gamma radiation used in frozen acaí pulps and its effects on phenolics and anthocyanin content as well as antioxidant activity. Conventional and organic acaí brands were also compared. Our results suggest that irradiation doses up to 5 kGy do not decrease total phenolic or anthocyanin content nor the pulp antioxidant activity comparing with non-irradiated pulps. Interestingly, the irradiated samples showed increases in the above-described analytes and antioxidant activity. The peak of this effect depended on the acaí (conventional or organic brands) and the analyte, ranging from 2,5 to 5 kGy. Conventional acaí had smaller or non-significant increases in all assays. While we could not evaluate if those changes arise from actual improvements or simply from better extraction of analytes after irradiation, we concluded that radiation doses up to 5 kGy can be used in acaí without harming its antioxidant properties. Still, further investigation is needed to be evaluated the viability of the irradiation process in the acaí industry.

ACKNOWLEDGEMENTS

The authors would like to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the grants, Embrapa – Food Technology, Rio de Janeiro, for the analysis and COPPE-UFRJ for the use of the irradiator.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nascimento WMO, Silva WR. Physiological behavior of acai seeds (*Euterpe oleracea* Mart.) submitted to dehydration. Comportamento fisiológico de sementes de acaí (*Euterpe oleracea* Mart.) submetidas à desidratação. Revista Brasileira de Fruticultura. Braz J Frutic. 2005;27(3):349-351. Portuguese Available:http://www.alice.cnptia.embrapa.br/alice/handle/doc/575389
2. Menezes EMS, Torres AT, Srur AUOS. Lyophilized acaí pulp (*Euterpe oleracea*, Mart.) nutritional value. Acta Amazonica. 2008;38(2):311-316. Available:https://doi.org/10.1590/S0044-59672008000200014
3. Alexandre D, Cunha RL, Hubinger MD. Açaí conservation through obstacle technology. Conservação do açaí pela tecnologia de obstáculos. Food Sci Technol. 2004;24:1114-1119. Available:http://dx.doi.org/10.1590/S0101-20612004000100021
4. Oliveira PAAC Silva IG, SML Furtado CM, Silva RF. In natura açaí beverage: Quality, pasteurization and acidification. Ciênc. Tecnol. Aliment. 2011;31(2). Available:https://doi.org/10.1590/S0101-20612011000200035
5. Albarici TR, Pessoa JC. Effects of heat treatment and storage temperature on the use of acaí drink by nutraceutical and beverage industries. Food Sci Technol. 2012;321:9-14. Available:http://dx.doi.org/10.1590/S0101-20612012005000026
6. Darnet S, Serra JL, Rodrigues AMC, Silva LHM. A high-performance liquid chromatography method to measure tocopherols in assai pulp (*Euterpe oleracea*). Food Res Int. 2011;44(7):2107-2111. Available:https://doi.org/10.1016/j.foodres.2010.12.039
7. Matias GS, Maia GA, Sousa PHM, Costa JMC, Figueiredo RW, Prado GM. Correlation between antioxidant activity and bioactive compounds from commercial acai pulps. Correlação entre atividade antioxidante e compostos bioativos de

polpas comerciais de acaí. Arch Latinoam Nutr. 2008;58(3):187-192. Portuguese

8. Borges GSC, Vieira FGK, Copettia C, Gonzaga LV, Zambiazi RC, Mancini Filho J, et al. Chemical characterization, bioactive compounds, and antioxidant capacity of jussara (*Euterpe edulis*) fruit from the Atlantic forest in Southern Brazil. Food Res Int. 2011;44(7):2128–2133. Available:https://doi.org/10.1016/j.foodres.2010.12.006
9. Kang J, Thakalia KM, Xie Chenghui, Kondo M, Tong Y, Ou B, et al. Bioactivities of acaí (*Euterpe precatoria* Mart.) fruit pulp, superior antioxidant and anti-inflammatory properties to *Euterpe oleracea* Mart. Food Chem. 2012a;133(3):671–677. Available:https://doi.org/10.1016/j.foodchem.2012.01.048
10. Schulz M, Borges GSC, Gonzaga LV, Seraglio SKT, Olivo IS, Azevedo MS, et al. Chemical composition, bioactive compounds and antioxidant capacity of juçara fruit (*Euterpe edulis* Martius) during ripening. Food Res Int. 2015;77:125–131. Available:https://doi.org/10.1016/j.foodres.2015.08.006
11. Kuskoski EA, Agustin GA, Morales Millán MT, Fett R. Tropical wild fruits and frozen fruit pulps: Antioxidant activity, polyphenols and anthocyanins. Frutos tropicais silvestres e polpas de frutas congeladas: Atividade antioxidante, polifenóis e antocianinas. Ciên Rur. 2006;1283–1287. Portuguese Available:http://hdl.handle.net/11441/67962
12. Brasil. Empresa brasileira de pesquisa agropecuária. Boletim de Pesquisa, 92. Preparation of dehydrated acai. Obtenção de acaí desidratado. 1988;14.
13. Lima ALS, Lima KSC, Coelho MJ, Silva JM, Godoy RLO, Pacheco S. Evaluation of gamma irradiation effects on carotenoids, ascorbic acid and sugar contents of buriti fruit (*Mauritia flexuosa* L.). Acta Amazon. 2009;39(3):649–654. Available:https://doi.org/10.1590/S0044-59672009000300020
14. Ornellas CBD, Goncalves MPJ, Silva PR, Martins RT. Consumer attitude towards food irradiation. Atitude do consumidor frente à irradiação de alimentos. Ciên Tecnol Aliment. 2006;26(1):211–213. ISSN 0101-2061. *On-line version* ISSN 1678-457X.
15. Uehara V. Effect of the gamma radiation in the green banana flour`s properties. Efeito da radiação gama em propriedades da farinha de banana verde. Master Science Thesis. Instituto de Pesquisas Energéticas e Nucleares Tecnologia Nuclear - Aplicações. USP. 2011;89.
16. Henry FC. Irradiation effects on meat flavor: A review. Meat Sci. 2009;8111–8114. Available:https://doi.org/10.1016/j.meatsci.2008.07.011
17. Brito ES, Araujo MCP, Alves RE, Carkeet C, Clevidence BA, Novoty JÁ. Anthocyanins present in selected tropical fruits: Acerola, jambolão, jussara and guajiru. J Agric Food Chem. 2007;55:9389-9394.
18. Garzón A, Narváez-Cuenca CE, Vincken JP, Gruppen H. Polyphenolic composition and antioxidant activity of açai (*Euterpe oleracea* Mart.) from Colombia. Food Chem. 2017;217:364-372. Available:https://doi.org/10.1016/j.foodchem.2016.08.107
19. Cheng Z, Moore J, Yu L. high-throughput relative DPPH radical scavenging capacity assay. J AgricFood Chem. 2006;54(1):7429-7436. Available:https://doi.org/10.1021/jf0611668
20. Wu X, Beecher GR, Holden JM, Haytowitz DB, Gebhardt, SE, Prior RL, et al. Lipophilic and hydrophilic antioxidant capacities of common foods in the united states. J Agric Food Chem. 2004;52(12):4026–37. Available:https://doi.org/10.1021/jf049696w
21. Dupureur CM, Sabaa-Srur AUO, Tran K, Shejwalker SPE, Smith R. ORAC values and anthocyanin content of brazilian and floridian acaí (*Euterpe oleraceae* Mart). Nat Prod J. 2012;2:99-103.
22. Huang D, Ou B, Hampsch-Woodill M, Flanagan JA, Prior RL. High-throughput assay of oxygen radical absorbance capacity (ORAC) using a multichannel liquid handling system coupled with a microplate fluorescence reader in 96-well format. J Agric Food Chem. 2002;50(16):4437-4444. Available:https://doi.org/10.1021/jf0201529
23. Coutinho RMP, Fontes EAF, Vieira LM, Barros FARD, Carvalho AFD, Stringheta PC. Physicochemical and microbiological characterization and antioxidant capacity of acaí pulps marketed in the states of

Minas Gerais and Pará, Brazil. Ciência Rural. 2017;47(1):e20151172. Available:http://dx.doi.org/10.1590/0103-8478cr20151172

24. Fernandes ETMB, Maciel VT, Souza MLD, Furtado CDM, Wadt LHDO, Cunha CRD. Physicochemical composition, color and sensory acceptance of low-fat cupuaçu and açaí nectar: Characterization and changes during storage. Food Sci Technol. 2016;36(3):413-420. Available:https://doi.org/10.1590/1678-457X.03415
25. Silva LB, Annetta FE, Alves AB, Queiroz MB, Fadini AL, Silva MG, et al. Effect of differently processed açai (*Euterpe oleracea* Mart.) on the retention of phenolics and anthocyanins in chewy candies. Int J Food Sci Technol. 2016;51(12):2603-2612. Available:https://doi.org/10.1111/ijfs.13245
26. Rogez H. Açaí: Preparo, composição e melhoramento da conservação. Belém: Universidade Federal do Pará. 2000;313. FAOUN agris.fao.org.
27. Rufino MSM, Alves RE, Brito ES, Pérez-Jiménez J, Sauracalixto F, Mancini-Filho J. Bioactive compounds and antioxidant capacities of 18 non-traditional tropical fruits from Brazil. Food Chem. 2010;121:996-1002. Available:https://doi.org/10.1016/j.foodchem.2010.01.037
28. Da Silva PPM. Conservation of juçara pulp (*Euterpe edulis*) submitted to gamma radiation, pasteurization, lyophilization and atomization. Conservação de polpa de juçara (*Euterpe edulis*) submetida à radiação gama, pasteurização, liofilização e atomização. Thesis. Centro de energia nuclear na agricultura, USP. Piracicaba, São Paulo. Brasil. 2013;259.
29. Pacheco-Palencia LA, Mertens-Talcott S, Talcott ST. Chemical composition, antioxidant properties, and thermal stability of a phytochemical enriched oil from açaí. J. Agric. Food Chem. 2008;56:4631-4636. Available:https://doi.org/10.1021/jf800161u
30. Ayed HL, Yu ML. Using gamma irradiation for the recovery of anthocyanins from grape pomace. Radiation Physics and Chem. 2000;57(3–6):277-279. Available:https://doi.org/10.1016/S0969-806X(99)00392-8
31. Alighourchi H, Barzegar M, Abbasi S. Anthocyanins characterization of 15 Iranian pomegranate (*Punica granatum* L.) varieties and their variation after cold storage and pasteurization. Europ. Food Res. Technol. 2008;227:881-887.
32. Kyung JK, Srinivasan P, Hunkim J, Choi J, Park HJ, Byun MW, et al. Structural and antioxidant properties of gamma irradiated hyaluronic acid. Food Chem. 2008;109(4): 763–770. Available:https://doi.org/10.1016/j.foodchem.2008.01.038
33. Abad LV, Relleve LS, Racadio CDT, Charito TA, Alumanda De la Rosa M. Antioxidant activity potential of gamma irradiated carrageenan. Appl Radiat Isotop. 2013;79(l):73-79. Available:https://doi.org/10.1016/j.apradiso.2013.04.035
34. Pradesh M, Prasad SV, Limaye A, Sharma A. Radiation-induced enhancement of antioxidant contents of soybean (*Glycine max* Merrill). J Agric Food Chem. 2004;52(11):3385-3388. Available:https://doi.org/10.1021/jf030793j
35. Sagar VR, Suresh K. Recent advances in drying and dehydration of fruits and vegetables: A review. J Food Sci Technol. – Mysore. 2010;47(1):15-26. Available:https://doi.org/10.1007/s13197-010-0010-8
36. O'Donnel CP, Tiwari BK, Patras A, Cullen PJ. Anthocyanin and ascorbic acid degradation in sonicated strawberry juice. J Agric Food Chem. 2008;56(21):10071-10077. Available:https://doi.org/10.1021/jf801824v
37. Castelucci ACL. Evaluation of the stability of bioactive compounds in native fruit pulps submitted to the irradiation process. Avaliação da estabilidade de compostos bioativos em polpas de frutas nativas submetidas ao processo de irradiação. PhD Thesis. 2015;133.
38. Schauss AG, Wu X, Prior RL, Ou B, Patel D, Huang D, et al. Phytochemical and nutrient composition of the freeze-dried amazonian palm berry, *Euterpe oleraceae* Mart. (acai). J Agric Food Chem. 2006;54(22):8598-8603. Available:https://doi.org/10.1021/jf060976g
39. Anjaya JGM, Hatnagar D, Eepak B. Gamma irradiation induced enhancement in isoflavones, total phenol, anthocyanin and antioxidant properties of varying seed coat colored soybean. J Agric Food Chem. 2010;58(7):4298-302. Available:https://doi.org/10.1021/jf904228e

40. Hussein SZ, Yusoff KM, Makpol S, Yusof YAM. Antioxidant capacities and phenolic compounds increases with gamma radiation in two types of Malaysian honey. Molecules. 2011;16:6378–6395. Available:https://doi.org/10.3390/molecules16086378
41. Kondapalli N, Sadineni V, Shekhar P, Variyar A, Vijay S, Obulama SR. Impact of gamma radiation on antioxidant capacity of mango (*Mangifera indica* L.) wine from eight Indian cultivars and the protection of mango wine against DNA damage caused by irradiation. Process Biochem. 2014;49: 1819–1830. Available:https://doi.org/10.1016/j.procbio.2014.07.015
42. Gomes SMC, Ghica ME, Rodrigues IA, Gila ES, Oliveira-Bretta AM. Flavonoids electrochemical detection in fruit extracts and total antioxidant capacity evaluation. Talanta. 2016;154:284-291. Available:https://doi.org/10.1016/j.talanta.2016.03.083
43. Bicudo MOP, Ribani RH, Beta T. Anthocyanins, phenolic acids and antioxidant properties of juçara fruits (*Euterpe edulis* M.) along the on-tree ripening process. Plant Foods Hum Nutr. 2014;69:142–147. Available:https://doi.org/10.1007/s11130-014-0406-0
44. Santos MFG, Mamede RVS, Rufino MSM, Brito ES, Alves RE. Amazonian native palm fruits as sources of antioxidant bioactive compounds. Antioxidants. 2015;4(3):591-602. Available:https://doi.org/10.3390/antiox4030591
45. Lee S, Kim TH, Lee EM, Lee MH, Lee HY, Chung BY. Degradation of cyanidin-3-rutinoside and formation of protocatechuic acid methyl ester in methanol solution by gamma irradiation. Food Chem. 2014;156: 312-318. Available:https://doi.org/10.1016/j.foodchem.2014.01.099
46. Silva PPM, Casemiro RC, Martin JGP, Carmo LF, Groppo-Ortiz V, Spoto MHF. Biochemical and sensory properties of juçara pulp submitted to gamma radiation. Commun Plant Sci. 2018;8:62–68. Available:http://dx.doi.org/10.26814/cps2018009

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/62279