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FOOD TECHNOLOGY

Gamma radiation and pasteurization on anthocyanin stability and antioxidant capacity of jussara pulp (*Euterpe edulis*) during storage

Carolina Tatagiba da Rocha[1] Evelyn Campos Paiva da Silva[1] Paulo César Stringheta[1] Daniele de Almeida Paula[2*] Sergio Antônio Fernandes[3] Marcos Roberto Moacir Ribeiro Pinto[4] Afonso Mota Ramos[1]

[1]Departamento de Ciência e Tecnologia de Alimentos, Universidade Federal de Viçosa (UFV), Viçosa, MG, Brasil.
[2]Instituto Federal de Educação, Ciência e Tecnologia do Paraná (IFPR), Campus Assis Chateaubriand, PR, Brasil. E-mail: daniele.paulaufv@gmail.com.
*Corresponding author.
[3]Departamento de Química, Universidade Federal de Viçosa (UFV), Viçosa, MG, Brasil.
[4]Instituto Federal de Educação, Ciência e Tecnologia do Espírito Santo (IFES), Campus Venda Nova do Imigrante, ES, Brasil.

ABSTRACT: The effects of gamma irradiation and pasteurization on the stability of anthocyanins and antioxidant capacity during storage of jussara pulp were investigated. Jussara pulp was divided into 6 portions: control (no treatment), irradiated pulp (2, 4, 6, 8 kGy) and pasteurized pulp (92 ºC/ 1 minute). Portions were stored at 4ºC for 60 days. The phenolic extract was prepared with a solution of methanol/water/ formic acid. The following analyses were performed every 15 days: contents of total phenolic compounds by Folin-Ciocauteau, cyanidin-3-glycoside and cyanidin-3-rutiniside by HPLC and antioxidant capacity (ABTS and DPPH). Total phenolics and anthocyanins decreased with the increasing irradiation dose and storage time. Pasteurization did not affect the phenolic concentration immediately after processing. However, the contents of TPC and cyanidin-3-rutiniside were reduced during storage of the pasteurized pulp. No processed samples presented characteristics similar to the control at the end of storage.
Key words: irradiation, flavonoids, phenolic compound, pasteurization.

Efeito da radiação gama e pasteurização na estabilidade de antocianinas e na capacidade antioxidante da polpa jussara (*Euterpe edulis*) durante o armazenamento

RESUMO: Os efeitos da radiação gama e pasteurização na estabilidade das antocianinas e na capacidade antioxidante durante o armazenamento da polpa de jussara foram avaliados. A polpa de jussara foi dividida em diferentes tratamentos: controle (sem tratamento), polpa irradiada (2, 4, 6, 8 kGy) e pasteurizada polpa (92 ºC / 1 minuto). Os tratamentos foram armazenados a 4ºC por 60 dias. O extrato fenólico foi preparado com uma solução de metanol / água / ácido fórmico. As seguintes análises foram realizadas a cada 15 dias: teores de compostos fenólicos totais por Folin-Ciocauteau, cianidina 51 3-glicosídeo e cianidina-3-rutinisida por HPLC e capacidade antioxidante (ABTS e DPPH). Os fenólicos totais e as antocianinas diminuíram com o aumento da dose de irradiação e do tempo de armazenamento. A pasteurização não afetou a concentração fenólica imediatamente após o processamento. No entanto, os teores de TPC e cianidina-3-rutinisida foram reduzidos durante o armazenamento da polpa pasteurizada. Nenhuma amostra processada apresentou características semelhantes ao controle ao final do armazenamento.
Palavras-chave: irradiação, flavonóides, composto fenólico, pasteurização.

INTRODUCTION

Jussara is the Brazilian name of fruit from *Euterpe edulis* Mart., a palm species native of the Brazilian Atlantic Forest. Processing consists of macerating the fruit with water, either manually or in a vertical pulper, so that the thin mesocarp and epicarp layers are separated from the seed (BICUDO et al., 2014; BORGES et al., 2013). The consumption of fresh pulp and its use as an ingredient have been encouraged in recent years due to its high nutritional value (SCHULZ et al., 2015). The commercialization of pulp also enables the generation of income for farmers of the Atlantic Forest.

Jussara has a high concentration of phenolic compounds, mainly anthocyanins. The main anthocyanins reported in the pulp are cyanidin-3-glycoside and cyanidin-3-rutinoside (BRITO et

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al., 2007; RUFINO et al., 2010). These compounds have antioxidant activity which acts to eliminate free radicals, molecules that damage biomolecules, making them important for the prevention of chronic diseases such as cancer (WOLFE et al., 2008). Because of this important biological function, it is important to know the stability of these compounds considering the different processing types to which the pulp may be subjected prior to marketing.

Due to the interest of consumers in foods more similar to fresh produce, the application of non-thermal methods for food preservation has been extensively studied (ARJEH et al., 2015). Irradiation is a non-thermal food preservation process effective in inactivating pathogenic bacteria and deteriorating microorganisms, increasing the shelf life of processed foods (MOREHOUSE, 2002). The effect of irradiation on anthocyanins in fruits depends on the composition of the food matrix, the irradiation dose applied and the structure of the molecule (ALIGHOURCHI et al., 2008), potentially causing an increase or reduction of the content of these compounds. This behavior has already been determined in several food matrices such as cherry juice (ARJEH et al., 2015), raspberry (GOLDING et al., 2014), blueberry (GOLDING et al., 2014) and wild jujube (NAJAFABADI et al., 2017).

Studies on fruit of the jussara tree have focused on quantification of the bioactive compounds and determination of antioxidant activity in pulp *in natura* and its health benefits (ROCHA et al., 2018; BERNARDES et al., 2019; FAVARO et al., 2018). However, few studies have evaluated the effects of processing and storage on the stability of phenolic compounds in jussara pulp. The objective of the present study was therefore to investigate the effects of gamma irradiation and pasteurization on stability of the main anthocyanins and on the antioxidant activity of the pulp from *Euterpe edulis*.

MATERIAL AND METHODS

Samples and Acquisition of the pulp

Jussara fruits (*Euterpe edulis*) were harvested in the city of Rio Novo (Espírito Santo, Brazil) in the last stage of maturation (peel with dark purple coloration), during the harvest of 2015. The fruits were selected, washed and weighed. They were then sanitized with chlorinated water (200 mg/L active chlorine) for 10 minutes and rinsed with chlorinated water (20 mg/L active chlorine) for 5 minutes. After sanitization, the fruits were immersed in hot water (40 ºC) for 10 minutes to soften the mesocarp. Pulping was performed as described by BICUDO et al. (2014), using a vertical pulper with addition of filtered water (0.6 liters/kg of fruit). The material obtained pulp was frozen until being subjected to pasteurization and irradiation.

Application of gamma irradiation and pasteurization to the pulp

The pulp was thawed and its pH adjusted to 3.6 with citric acid. It was then divided into 6 portions: control (untreated pulp), irradiated pulp (2, 4, 6, 8 kGy), and finally pasteurized pulp. Samples were prepared 3 times for each treatment.The irradiation treatment was applied at the different doses for each serving at a mean dose rate of 3.83 kGy/hour. The irradiator used had a Cobaldo 60 source, model IR-214 (Nordion, Canada).

For pasteurization, glass bottles containing the pulp were placed in a water bath until reaching a temperature of 92 ºC for 1 minute, where the temperature was measured with the aid of a thermometer placed in the center of a bottle. After processing the samples were stored in a BOD at 4 ºC for 60 days and physical-chemical analyses were performed every 15 days.

Raw material analysis

Analyses of pH, titratable acidity, soluble solids and moisture were carried out using pulp *in natura* according to the methodologies described by AOAC (2005).

Preparation of the phenolic extract for analysis

The phenolic compounds were extracted from 5 grams of pulp with 20 mL of a mixture of methanol/water/formic acid (70:28.5:1.5) using an ultrasonic bath at 25 ºC for 10 minutes. The extract was centrifuged (2000 g x 10 minutes) and the supernatant filtered. The residue was extracted 3 more times with a mixture of methanol/water/formic acid (50:48.5:1.5). The four filtrates were combined, concentrated in a rotary evaporator (35 ºC) (REBELLO et al., 2013) for methanol evaporation and the final volume completed to 25 mL with distilled water.

Total phenolic compounds

The content of total phenolic compounds (TPC) was estimated using adaptations of the method reported by SINGLETON & ROSSI (1965). First, the Folin Ciocalteau reagent was diluted in distilled water (1/10, v/v). Then 2 mL of the extract was diluted with distilled water in a 10 mL volumetric flask. An aliquot (600 µL) of the diluted extract was added to

3 mL of the previously prepared Folin Ciocalteau reagent. This mixture was stirred and after three minutes, 2.4 mL of saturated sodium carbonate (7.5% w/v) were added. The spectrophotometer reading at 760 nm was performed after leaving the sample at rest for 1 hour in the absence of light. The content of total phenolic compounds was expressed in dry basis.

Analysis of anthocyanin by UHPLC-DAD

Anthocyanins were determined using a Thermo Scientific UHPLC system equipped with ChromQuest software, autoinjector (Accela autosample), pump (Accela 600) and UV-Visible detector (Accela PDA). A Hypersil Gold UHPLC column (50 x 2.1 mm, 1.9 µ) from Thermo Scientific was used for separation.

Chromatographic conditions were adapted from BRITO et al. (2007). The extract was filtered through 0.45 µm PVDF Millex® membrane filters and 10 µL were injected into the chromatographic system. The flow rate was 300 µL min^{-1}. Solvents A (10% formic acid in water) and B (methanol) were used, which were eluted at room temperature with isocratic flow of 95% A for 10 minutes, followed by a gradient from 95 to 90% A until 15 minutes and then increased to 95% A until 20 minutes. Anthocyanins were identified by comparing their retention times with standards. Samples mixed with the standard were injected for confirmation of the retention time. Chromatograms at 530 nm were used for quantification, and cyanidin-3-glucoside and cyanidin-3-rutinoside were used as external standards. The content of cyanidin-3-glucoside and cyanidin-3-rutinoside was expressed in dry basis.

Radical scavenging of the free radical DPPH

Sequestration activity of the DPPH˙ radical was determined according to a methodology adapted from BRAND-WILLIAMS et al., (1995). The phenolic extract (2 mL) was pre-diluted in methanol using a 10 mL volumetric flask. For the reaction, 100 µL of the standard or diluted extract was mixed with 2.9 mL of the previously prepared DPPH˙ radical and incubated for 90 minutes at room temperature. This reaction time was determined in preliminary tests. Then, the absorbance values were read in a spectrophotometer at 515 nm using methanol as the blank. The DPPH˙ sequestration activity values were determined using a standard Trolox methanol solution curve. The results were expressed in µmol of Trolox equivalent/ gram of dry matter.

Antioxidant activity by the $ABTS^{+\bullet}$ method

Determination of the antioxidant activity via the $ABTS^{+\bullet}$ method was adapted from Re et al. (1999). First, the $ABTS^{+\bullet}$ radical was prepared, at least 16 hours before analysis, by the reaction of 2.45 mM potassium persulfate with 7 mM ABTS. The formed radical was diluted in ethanol (80%) until an absorbance of 0.700 + 0.01 was obtained at the wavelength of 734 nm. The extract (0.2 mL) was diluted in a 10 mL volumetric flask with ethanol (80%). Then, a 500 µL aliquot of the diluted extract was transferred to test tubes containing 3.5 mL of the $ABTS^{+\bullet}$ radical. Absorbance values were read at 734 nm after 90 minutes (time required for reaction stabilization) of reaction, using ethanol (80%) as the blank. Trolox solutions at concentrations of 10 to 200 µM were used as an external standard. The results were expressed in µmol of trolox equivalent/ gram of dry matter.

Statistical analysis

The effect of irradiation on the bioactive compounds was evaluated using a factorial (5 doses x 5 times) in a completely randomized design. The data was adjusted to multiple regression models and response surfaces were constructed for the significant models ($P < 0.05$).

For the pasteurization experiment a completely randomized design was used. Regression models were fitted to the generated data. The Dunnett test at 5% probability was used immediately after processing and at the end of the 60 day shelf life to compare the pasteurized sample with the control.

Due to the large amount of data, a principal component analysis (PCA) was performed to simultaneously observe the correlation between the effects of the treatments and storage time. The PCA was conducted using the statistical program Gemoface. Correlation analyses were conducted by means of the Pearson coefficient.

RESULTS AND DISCUSSION

Characterization of the raw material

Table 1 presents the chemical composition of the jussara pulp.

Since there is no specific legislation on jussara pulp, the parameters were compared with data from literature. The pH of the pulp is within the limits stipulated for açaí pulp (BRASIL, 2000). The soluble solids content was similar to that reported by SILVA et al., (2013) for jussara pulp from São Paulo. The titratable acidity was higher than that reported for pulp produced in Espírito Santo, while the moisture content was lower than that of the same pulp (PAIM et al., 2016).

Table 1- Physico-chemical composition of the jussara pulp at the begnning of the experiment.

Parameter	Result	Literature	Source
pH	4.7	4.0 a 6.2	BRASIL (2000)
Soluble solids[1]	2.8	2.01	SILVA et al. (2013)
Acidity[2]	3.0	1.67	PAIM et al. (2016)
Moisture (%)	88.8	93.8	PAIM et al. (2016)

[1]ºBrix; [2]% Citric acid.

Fitting of the models

For the irradiation experiment the effect of storage time and irradiation dose on the content of TPC (total phenolic compounds), cy-3-rut, cy-3-glc, ABTS and DPPH were tested using a multiple regression model. A simple regression model was used for evaluating the effect of storage time in the pasteurization experiment. Table 2 shows the significant regression models, coefficient of determination (R^2) and lack of fit for the responses of the irradiated and pasteurized pulp.

The lack of fit was not significant ($P > 0.05$), which indicates that the models were adequate to predict the data variation. The coefficient of determination (R^2) ranged from 78.24% to 97.92%, indicating that all models explain the variability of the data. For the irradiated pulp, the first-order negative linear effect of storage time (x_1) and irradiation dose (x_2) was significant ($P < 0.05$) for TPC, cy-3-rut and cy-3-glc. A significant effect was obtained only for storage time with regards to the variable ABTS. It can be seen from the regression coefficients that accompany x_1 and x_2, that cy-3-rut is the variable most affected by storage time and irradiation dose. Conversely, TPC is the variable least influenced by these factors.

For the pasteurized pulp, the first-order negative linear effect of storage time (x_1) was significant for TPC and cy-3-rut. Cy-3-rut was more affected by storage time than TPC.

Table 3 shows the average values obtained in the analyses of total phenolic compounds, anthocyanins and antioxidant capacity for each treatment point.

Effect of irradiation

The storage time and irradiation dose influenced the content of total phenolic compounds. It can be observed from the regression coefficients (Table 2) that the effect of irradiation dose on TPC is greater than the effect of storage time. According to the model, immediately after the irradiation application, when the irradiation dose increases from 0 to 8 kGy, a 2.30% decrease in the TPC concentration is observed.

During storage of the irradiated pulp there was a decrease in the TPC. It is observed that during storage the higher the dose applied, the lower the TPC

Table 2 - Adjusted equations and calculated statistical parameters for chemical analyses of the irradiated and pasteurized pulp.

----------Irradiation----------			
Variable	Adjusted equations	R^2	FAj
TPC	$Y = 55.681 - 0.0726x_1 - 0.1594x_2$	91.95%	0.977^{ns}
cy-3-rut	$Y = 805.0 - 4.433x_1 - 16.23x_2$	97.92%	0.997^{ns}
c-3-glc	$Y = 172.97 - 1.2933x_1 - 3.083x_2$	98.97%	0.999^{ns}
ABTS	$Y = 503.6 - 1.125x_1$	78,24%	0.992^{ns}
----------Pasteurization----------			
Variable	Adjusted equations	R^2	FAj
TPC	$Y = 53.25 - 0.0869x_1$	82.24%	0.611^{ns}
cy-3-rut	$Y = 739.1 - 2.89x_1$	84.62%	0.864^{ns}

x_1, time; x_2, dose; R^2, determination coefficient; FAj, Lack of adjustment; TPC, Total Phenolic Compounds; cy-3-rut, cyanidin-3-rutinoside; cy-3-glc, cyanidin-3-glucoside; ^{ns}, Not significant ($P > 0,05$).

Table 3 - Mean values obtained in the analyses of total phenolic compounds, anthocyanins and antioxidant capacity for the untreated, irradiated and pasteurized pulp.

Parameters	Time (Days)	----------Dose (kGy)----------					Pasteurization
		0	2	4	6	8	
TPC	0	54.30	55.03	54.31	54.99	54.95	52.61
	15	54.81	54.67	53.50	54.09	53.78	51.97
	30	55.04	53.41	51.72	53.19	53.17	51.32
	45	52.10	51.79	52.04	51.00	50.87	50.49
	60	52.98	50.83	49.17	50.31	49.58	46.83
cy-3-rut	0	781.44	747.44	728.88	709.52	684.58	706.04
	15	772.91	698.74	692.11	615.54	613.64	742.84
	30	707.15	641.23	603.60	557.95	622.47	646.92
	45	607.80	571.77	541.74	495.01	466.89	607.87
	60	566.58	472.16	451.83	426.96	426.68	556.87
cy-3-glc	0	167.33	165.17	162.23	156.55	150.58	136.20
	15	159.70	147.19	145.21	125.86	127.74	140.06
	30	143.51	128.48	122.49	111.06	117.11	128.34
	45	110.65	104.30	104.50	90.35	86.72	115.73
	60	99.46	82.28	82.02	78.24	79.57	115.44
DPPH	0	204.37	199.77	194.36	196.68	196.41	190.13
	15	249.94	245.22	242.06	245.20	246.20	238.93
	30	231.19	223.29	215.07	216.76	224.21	217.71
	45	219.59	215.80	208.01	219.24	205.87	208.43
	60	234.81	217.22	222.62	223.18	224.32	212.03
ABTS	0	514.12	512.26	495.34	509.62	501.86	466.89
	15	527.81	480.56	444.73	453.48	446.52	450.61
	30	514.86	496.17	490.02	487.15	449.34	470.84
	45	474.06	460.29	463.08	439.73	454.00	453.68
	60	458.58	396.17	427.92	443.16	411.53	413.77

*TPC (Total phenolic compounds - mg gallic acid/g dry basis); DPPH (µMol/g dry basis); ABTS (µMol/g dry basis); cy-3-rut (cyanidin-3-rutinoside - mg cy-3-rut /100g dry basis); cy-3-glc (cyanidin-3-glucoside - mg cy-3-glc /100g dry basis).

content at the end of the 60 days of storage (Figure 1). The loss with storage time varied from 7.82% in the control to 10.69% in the pulp irradiated with 8 kGy.

The storage time and the irradiation dose influenced the content of the anthocyanins cy-3-rut and cy-3-glc. It can be observed from the regression coefficients (Table 2) that the effect of irradiation dose on anthocyanin concentration is greater than the effect of storage time. Influence on cy-3-rut was greater influence than that on cy-3-glc regarding both factors.

After processing, when the irradiation dose increased from 0 to 8 kGy, there were reductions of 14.26 and 16.13% in the contents of cy 3-glc and cy 3-rut, respectively. The content of anthocyanins decreased during the storage period, and the higher the dose applied the greater the losses of cy-3-rut and cy-3-glc (Figure 2 and 3). In the present study, after 60 days of storage the cy-3-glc content decreased from 44.86% (control) to 59.12% in the pulp irradiated with the 8 kGy dose. The cy-3-rut content decreased by 33.04% in the control sample to 49.17% in that irradiated with 8 kGy.

Processing and storage time are factors that can modify the content of phenolic compounds in fruits after harvest. In the present study, there was a decrease in the content of total phenolic compounds and individual anthocyanins with increased irradiation dose (Figure 1-3), indicating that this processing method negatively affects the quality of the pulp. During irradiation, free radicals are formed by the process of water radiolysis (SEVILLA et al., 2016). These radicals have high reactivity and can oxidize phenolic compounds, which in turn act as natural antioxidants (SHAHBAZ et al., 2014).

It can be observed from the regression coefficients presented in table 2 that the irradiation dose has a different intensity effect on each compound

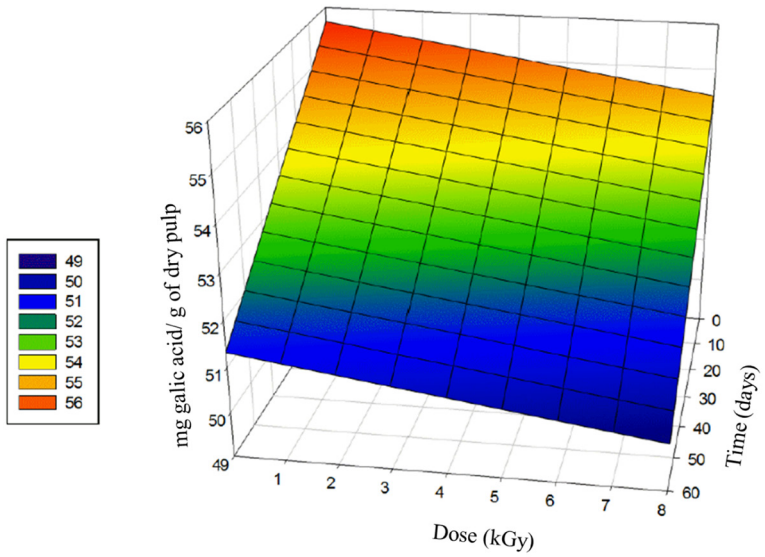

Figure 1 - Response surface plotted to demonstrate the combined effect of the irradiation dose and storage time on total phenolic compounds.

(TPC, cy-3-rut and cy-3-glc). This is because free radicals can act differently on individual phenolic compounds according to the molecule structure (ALIGHOURCHI et al., 2008; ITO et al., 2016).

During storage, the higher the dose applied the lower the content of TPC, cy-3-rut and cy-3-glc. This is probably due to the presence of oxidative enzymes, such as polyphenoloxidase, which use phenolic compounds as a substrate and are not inactivated by the irradiation process (KIM et al., 2007; KRAPFENBAUER et al., 2006). In addition, free radicals cause membrane degradation due to loss of phospholipids. This effect is potentiated by the storage time, i.e., the content of phospholipids in the membrane is more rapidly reduced over time the higher the dose of irradiation initially applied (VOISINE et al., 1991; VOISINE et al., 1993). Therefore, decomposition of the cell membrane causes contact between oxidative enzymes and phenolic compounds (BANERJEE et al., 2015), resulting in greater loss of these components when increasing the irradiation dose applied and the storage time.

Effect of pasteurization

There was a significant effect ($P < 0.05$) of storage time on the TPC of the pasteurized pulp (Table 2), resulting in a 9.79% decrease in TPC during the storage period according to the proposed model. After 60 days of storage, the content of phenolic compounds was significantly lower in pasteurized pulp than in the control (Table 3). There was no significant difference in the cy-3-rut and cy-3-glc contents between the control and pasteurized pulp immediately after processing (Table 3).

There was a significant effect ($P < 0.05$) of storage time only on the cy-3-rut content of the pasteurized pulp (Table 2), while the cy-3-glc did not change over time. There was a 21.54% loss in cy-3-rut during storage at 4 ºC for 60 days. Despite this loss, in the present work, at the end of storage the pasteurized pulp showed no significant difference in cy-3-rut concentration when compared to the control (Table 3).

The pasteurization process did not have an immediate effect on the content of TPC, cy-3-rut and cy-3-glc. Conversely, the storage time had a negative effect on the content of TPC and cy-3-rut (Table 2). Heat causes increased oxidation reactions with consequent reduction of the phenolic content (ZHANG et al., 2012). Due to the increase in temperature, there occurs thermal degradation of polysaccharides of the cell wall (LLANO et al., 2003), causing greater contact between phenolic compounds and oxygen. For the specific case of anthocyanins, deglycosylation followed by anthocyanidin cleavage occurs, forming phenolic compounds of lower molecular weight (SADILOVA et al., 2006) or polymerization reactions

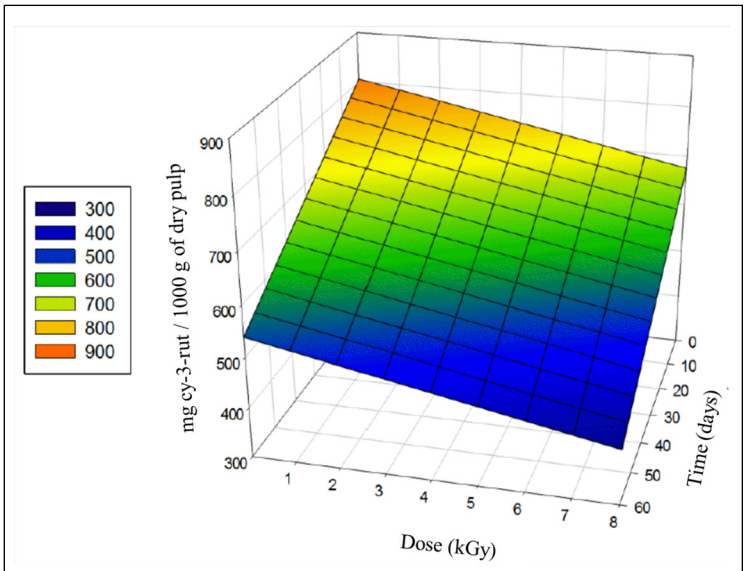

Figure 2 - Response surface plotted to demonstrate the combined effect of the irradiation dose and storage time on cy-3-rut.

that form unstable high molecular weight compounds (CHOI et al., 2002; OLIVEIRA et al., 2014; PACHECO-PALENCIA et al., 2007).

Antioxidant capacity

The effect of the irradiation dose and storage time on the sequestration activity of the DPPH radical was not significant ($P > 0.05$). Therefore, these factors did not influence the scanning percentage of the DPPH radical. Only the storage time had a significant effect ($P < 0.05$) on the antioxidant activity of the irradiated jussara pulp, determined by the ABTS method (Table 2). The ability to eliminate free radicals decreased over the storage time.

Pasteurization did not influence the antioxidant activity determined by the ABTS and DPPH methods of the pasteurized jussara pulp immediately after processing (Table 2). The storage time had no significant effect ($P > 0.05$) on the ability to eliminate free radicals from the pasteurized pulp (data not shown).

There was no correlation between the DPPH variable and anthocyanins (cy-3-rut and cy-3-glc) ($P > 0.05$). The correlation between DPPH and total phenolic compounds was considered low ($r=0.215$). There was a positive correlation between the antioxidant capacity by the ABTS method with cy-3-rut ($r= 0.632$), cy-3-glc ($r= 0.466$) and TPC ($r= 0.403$). Therefore, the anthocyanins, and mainly cy-3-rut, are the components that contribute most to the antioxidant capacity of jussara pulp.

Principal component analysis

The principal component analysis was used to simultaneously assess the effect of irradiation and pasteurization, initially evaluated separately, and storage time on phenolic compounds, individual anthocyanins and antioxidant capacity of jussara pulp. The points in figure 4 were coded with the type of treatment (C, control; I2, 2 kGy; I4, 4 kGy; I6, 6 kGy; I8, 8 kGy; P, pasteurization) followed by storage time (T0, immediately after processing; T15, 15 days; T30, 30 days; T45, 45 days; T60, 60 days). The two main components together explained 89.02% (PC1 67.86% and PC2 21.16%) of the variability contained in the data (Figure 4). The first principal component is most correlated with the TPC, cy-3-glyc, cy-3-rut and ABTS. On the other hand, DPPH is strongly correlated with the second principal component.

It was possible to identify 4 distinct groups. The first group consists of the treatments corresponding to the zero storage time (CT0, I2T0, I4T0, I6T0, I8T0 and PT0). This group was positively correlated with TPC, cy-3-glc, cy-3-rut and ABTS, indicating that these compounds are present in greater proportion in these samples and are responsible for the difference between these treatments and the others. The second group is represented by all samples from the

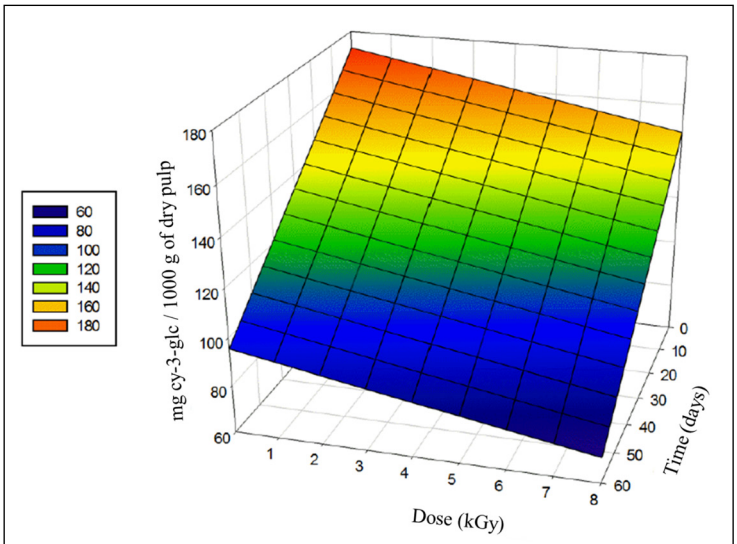

Figure 3 - Response surface plotted to demonstrate the combined effect of the irradiation dose and storage time on cy-3glc.

15th day of storage (CT15, I2T15, I4T15, I6T15, I8T15 and PT15) and the control on the 30th day (CT30). This group has a correlation with TPC, cy-3-glc, cy-3-rut and ABTS, but the samples are mainly related to DPPH. In the third group were 5 samples from the 30th day (I2T30, I4T30, I6T30, I8T30 and PT30), 4 samples from the 45th day (CT45, I2T45, I4T45 and PT45) and 1 sample from the 60th (CT60). This group is positioned near the center of the graph, indicating little correlation with TPC, cy-3-glc, cy-3-rut, ABTS and DPPH. The fourth group consisted of 2 samples from the 45th day (I6T45 and I8T45) and 5 samples from the 60th day (I2T60, I4T60, I6T60, I8T60 and PT60), presenting strong negative correlation with TPC, cy-3-glc, cy-3-rut and ABTS.

The first principal component, positively correlated with TPC, cy-3-glc, cy-3-rut and ABTS, clearly differentiates the zero storage time samples (group 1, 3rd quadrant) from the 60th day of storage (group 4), indicating that the content of total phenolic compounds, anthocyanins and antioxidant capacity is higher at the beginning of storage. According to this result, the storage time factor appears to have a greater effect than the type of treatment on the phenolic composition of the pulp, especially up through the 30th day of storage. Most samples from the 30th and 45th days appear in the same group (group 3), indicating that they are similar to each other.

The samples from the 45th day of storage irradiated with doses of 6 and 8 kGy (I6T45 and I8T45) show greater similarity to samples of the 60th day, indicating that at the end of the storage time the effect of the irradiation dose may be higher than at the beginning of storage. This result is in agreement with the regression models, again indicating that the effect of the dose is potentiated by storage time (VOISINE et al., 1991, 1993).

According to the PCA, during the period up to 30 days the effect of irradiation and pasteurization has a similar intensity. As of the 45th day of storage, the higher irradiation doses (6 and 8 kGy) appear to have a more intense effect on the phenolic composition of the pulp than pasteurization. Finally, all samples as of the 60th day of storage presented a difference in relation to the control sample (CT60), indicating that all treatments were harmful to the phenolic content and antioxidant capacity of jussara, according to the ABTS method.

CONCLUSION

The irradiation process had a detrimental effect on the total phenolic compounds, cyanidin-3-glycoside, cyanidin-3-rutiniside and the antioxidant capacity, determined by the ABTS method, of jussara pulp throughout the entire storage period at 4 ºC. Pasteurization did not change the cyanidin-3-rutinoside and cyanidin-3-glycoside contents and antioxidant capacity of the pulp when compared to the control after 60 days of refrigerated storage.

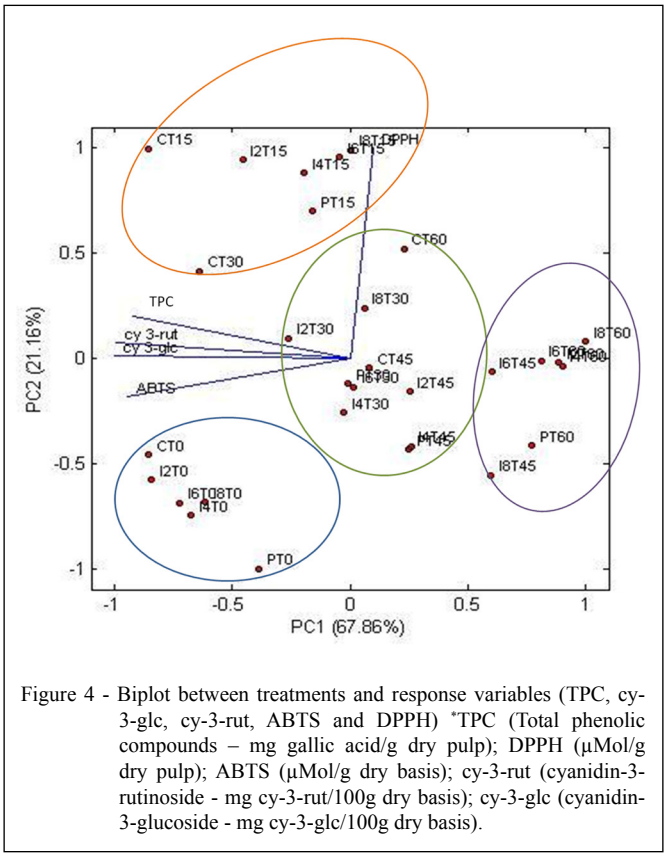

Figure 4 - Biplot between treatments and response variables (TPC, cy-3-glc, cy-3-rut, ABTS and DPPH) *TPC (Total phenolic compounds – mg gallic acid/g dry pulp); DPPH (µMol/g dry pulp); ABTS (µMol/g dry basis); cy-3-rut (cyanidin-3-rutinoside - mg cy-3-rut/100g dry basis); cy-3-glc (cyanidin-3-glucoside - mg cy-3-glc/100g dry basis).

The types of processing affected individual anthocyanins differently. Cyanidin-3-glycoside was more stable during storage of pasteurized pulp than cyanidin-3-rutinoside. Conversely, there was less loss of cyanidin-3-rutinoside in the irradiated pulp during storage.

According to analysis of the principal components, through the 30th day of storage the different types of processing had a similar effect on the samples. As of the 45th day the highest irradiation doses appear to be more harmful than the other treatments. A study with longer storage times is required to confirm these results.

The study of stability of these compounds allows for reducing losses during processing and storage of the raw material. According to the data presented, the pasteurization process is most suitable for reducing the loss of phenolic compounds in refrigerated jussara pulp.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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