Total Anthocyanin Content in Intact Açaí (*Euterpe oleracea* Mart.) and Juçara (*Euterpe edulis* Mart.) Fruit Predicted by Near Infrared Spectroscopy

Gustavo H. de A. Teixeira¹

Universidade Estadual Paulista (UNESP), Faculdade de Ciências Agrárias e Veterinárias, Departamento de Produção Vegetal. Via de Acesso Prof. Paulo Donato Castellane, s/n. Jaboticabal, CEP 14884-900, São Paulo, Brazil

Valquiria G. Lopes

Empresa Brasileira de Pesquisa Agropecuária, Instrumentação Agropecuária, Rua XV de Novembro 1452, São Carlos, CEP 13560-970, São Paulo, Brazil

Luís C. Cunha Júnior

Universidade de São Paulo, Faculdade de Ciências Farmacêuticas de Ribeirão Preto, Departamento de Análises Clínicas, Toxicológicas e Bromatológicas. Av. do Café, s/n. Campus Universitário da USP, Ribeirão Preto, CEP 14040-903, São Paulo, Brazil

José D.C. Pessoa

Empresa Brasileira de Pesquisa Agropecuária, Instrumentação Agropecuária, Rua XV de Novembro 1452, São Carlos, CEP 13560-970, São Paulo, Brazil

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Abstract. Açaí (*Euterpe oleracea* Mart.) and juçara (*Euterpe edulis* Mart.) palms are native to Brazil and these species are rich in anthocyanins. The methods applied to determine anthocyanins are time-consuming, generate chemical residues, and do not fit in modern on-line grading machines. As near infrared (NIR) spectroscopy has been used as a nondestructive method to determine anthocyanin, the objective of this study was to use NIR spectroscopy to predict total anthocyanin (TA) in intact açaí and juçara fruits. Spectra were collected using a Fourier transform (FT)-NIR spectrophotometer in the diffuse reflectance (4,000–10,000 cm⁻¹) and TA reference data were obtained using the Association of Official Analytical Chemists (AOAC) method. Different treatments were applied to spectra and spectral data sets were correlated with TA by using partial least squares (PLSs) regression algorithm. The global-PLS model obtained with açaí and juçara spectra resulted in a root mean standard error of prediction (RMSEP) of 10.05 g·kg⁻¹. However, this model was not adequate for TA levels found in açaí fruits, therefore individual models were developed. The açaí-PLS model proved to be more adequate, as RMSEP was reduced to 3.56 g·kg⁻¹. On the other hand, the RMSEP obtained with the juçara-PLS model (6.59 g·kg⁻¹) was almost the same of the global model. NIR spectroscopy can be used to adequately predict TA content in intact açaí and juçara fruits and this method could be used as an analytical procedure to monitor their quality.

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¹Corresponding author. E-mail: gustavo@fcav.unesp.br.

Brazil has great biodiversity of plants, and many fructiferous species are rich in anthocyanins (Alves et al., 2008). Among these species, açaí (*Euterpe oleracea* Mart.) and juçara palm trees (*Euterpe edulis* Mart.) produce small, deep purple fruits due to the presence of anthocyanins (Gallori et al., 2004; Iaderoza et al., 1992; Lichtenthäler et al., 2005; Pacheco-Palencia et al., 2007; Pozo-Insfran et al., 2004; Schauss et al., 2006), with juçara been considered richer in TA (1347 mg 100 g⁻¹) than açaí fruit (336 mg 100 g⁻¹).

Regarding anthocyanins determination in açaí and juçara fruit, a range of analytical

procedures have been used, e.g., visible spectroscopy (Bobbio et al., 2000) and chromatographic techniques (Gallori et al., 2004; Iaderoza et al., 1992; Lichtenthäler et al., 2005; Pacheco-Palencia et al., 2007; Pozo-Insfran et al., 2004; Schauss et al., 2006). All of which are relatively slow, thereby limiting their usefulness for determining the levels of these compounds at the moment they are received by the industry. On the other hand, nondestructive methods can be applied to overcome these limitations and NIR spectroscopy is a fast, nondestructive, noninvasive method with a high penetration of radiation (Pasquini, 2003). Therefore, its use as analytical methods may exhibit near universal application, as it can potentially be applied to determine the anthocyanin levels of açaí and juçara palm fruits.

Various studies have been performed using NIR spectroscopy to evaluate the quality of fruits (Nicolai et al., 2007). In terms of anthocyanins, NIR spectroscopy has been used on intact apples (Merzlyak et al., 2003), grapes (Damberg et al., 2006; Gishen et al., 2005; Nazarov et al., 2005), blueberries (Sinelli et al., 2008), cherries (Zude et al., 2011), olives (Bellincontro et al., 2012), and also açaí and juçara (Inácio et al., 2013).

Regardless the case, robust models are necessary when the prediction accuracy will be related to unknown external factors. In fruit and vegetables, it is probably the most important factor, as fruits might be subjected to within-tree variability, within-orchard variability, orchard variability, fruit age, and seasonal variability (Peirs et al., 2002).

We showed that it is possible to use NIR spectroscopy as a nondestructive method to determine TA in intact açaí and juçara (Inácio et al., 2013). However, we did use data of harvest season only (2010). To improve the robustness of the models already developed, the objective of this study was to incorporate the data obtained from a different harvest season (2011) into the data set and develop new and more robust model for TA prediction by means of NIR spectroscopy in intact açaí and juçara fruits.

Material and Methods

Plant material. Açaí and juçara fruits were collected in 2010 (Inácio et al., 2013) and 2011, with the fruits from 2011 harvested in three periods (initial, middle, and end of the harvest season). All fruits were harvested in a commercial maturity stage with skin completely purple (Rogez, 2000).

2010 harvest. In this harvest, fruits of 14 genotypes of the juçara and açaí palms were collected; seven of each species. Fruits of the juçara palm were collected in June 2010 at the town of Jaboticabal, São Paulo, Brazil. The açaí fruits were collected in the same month, both at the town of Ubatuba, São Paulo (five plants), and Jaboticabal, São Paulo (two plants). With these fruits we developed the initial models (Inácio et al., 2013).

2011 harvest. With the aim of adding more variability into the data set, variations arising

from other harvest season and period of harvest, fruit were harvested at the beginning (February, açaí n = 1 and juçara n = 4 genotypes), middle (May, açaí n = 4 and juçara n = 4 genotypes), and at the end (June, açaí n = 5 and juçara n = 5 genotypes) of the harvest season. Açaí fruits were collected at three localities; namely Ubatuba, Jaboticabal, and Américo Brasiliense, São Paulo State. Juçara fruits were collected at four localities; Ubatuba, Jaboticabal, Ribeirão Preto, and Américo Brasiliense, São Paulo State.

Transport and preparation of the samples. After harvest the fruits were placed into plastic bags, rapidly transported to the FCFRP-USP, kept at room temperature ($\approx 25^\circ\text{C}$) with the goal of stabilizing the temperature of the different samples. For each sample (genotype), a group of 10 fruits were randomly chosen and each fruit was individually analyzed in terms of diffuse reflectance in the NIR region. Next, the fruits were frozen for analysis of TA content. In total, it was used 139 fruits in 2010 and 230 in 2011.

Calibration and prediction groups. Samples were divided into calibration and prediction group. For the calibration, 80% of the samples (294, 134, and 160 spectra for the global, açaí and juçara models, respectively) were selected (Table 1). The remaining 20% of the samples (74, 34, and 40 spectra for the global, açaí and juçara models, respectively) were selected as the prediction group (Table 1). The division into calibration and prediction set was carried out by applying the classic Kennard–Stone selection algorithm to the NIR spectra (Kennard and Stone, 1969).

Spectra acquisition. The diffuse reflectance spectra in the NIR region with FT were obtained using a FT-IR Spectrum 100 N (PerkinElmer, Shelton, CT) spectrometer. Fruits were set on a polytetrafluorethylene support with an aperture of 0.5 cm diameter on a near infrared reflectance accessories (NIRA) (PerkinElmer, PN L125403L). Data were obtained in the wavenumber range from 4,000 to 10,000 cm^{-1} , with 64 scans at a spectral resolution of 2 cm^{-1} with three determinations per fruit, making. The spectra were saved as SP extension files, and the Unscrambler® version X.1 (CAMO, Oslo, Norway) was used to manipulate them.

TA content reference method. After NIR spectra acquisition from individual fruit, the fruits were rapidly frozen and stored at -18°C . The pH differential method, applicable to the determination of monomeric anthocyanins in fruit as cyanidin-3-glucoside, was used as the reference method (A.O.A.C.,

Table 1. Average total anthocyanin, expressed in cyanidin-3-glucoside ($\text{g}\cdot\text{kg}^{-1}$ w/w), of açaí (*Euterpe oleracea* Mart.) and juçara (*Euterpe edulis* Mart.) fruit from the State of São Paulo and collected across two harvests and at different periods of the year.^z

	n	Average	SD ^y	Maximum	Minimum
2010					
Açaí	68	10.44 b ^x	6.22	23.90	1.49
Juçara	70	33.22 a	21.62	80.36	0.33
2011					
Açaí	100	12.04 b	8.26	42.30	0.50
Juçara	130	25.55 a	19.01	75.04	0.70
Global (açaí+ juçara)					
Calibration set	294	20.13 a	17.45	80.36	0.33
Prediction set	74	21.25 a	18.84	69.19	1.49
Açaí					
Calibration set	134	11.48 a	7.65	42.30	0.50
Prediction set	34	11.07 a	7.08	23.18	1.72
Juçara					
Calibration set	160	26.97 a	20.54	80.39	0.33
Prediction set	40	31.58 a	18.35	68.60	2.40

^zPopulations selected using Kennard–Stone algorithm.

^yStandard deviation.

^xAverages followed by the same letter, in the column for each harvest, are significantly different according to test F ($P < 0.05$).

Fig. 1. Raw near infrared spectra of intact açaí and juçara fruit. The spectra were acquired using a fourier transform-infrared (FT-IR) Spectrum 100 N (PerkinElmer, Shelton, CT) spectrometer on the spectral band from 4,000 to 10,000 cm^{-1} .

2006). Total anthocyanin extraction and determination were carried out according to Inácio et al. (2013).

Preprocessing. The 1107 spectra (417 from 2010 and 690 from 2011) were reduced to their average, yielding an average spectrum per fruit, and reducing the number of spectra to 369 (one mean spectrum per fruit). Next, the spectra underwent the following preprocessing techniques: 1). standard normal variate

(SNV), in accordance with Barnes et al. (1993) and Naes et al. (2002); 2) De-trending (Barnes et al., 1989; Barnes et al., 1993; Naes et al., 2002); first derivative of Savitzky–Golay (Savitzky and Golay, 1964) (second polynomial order with 11 smoothing points). The reduction of the FT-NIR spectra to their averages, and preprocessing techniques were performed using the Unscrambler® X.1 software.

Chemometrics. The Unscrambler® X.3 software was used to develop the PLSs and principal component regression (PCR) models using random cross validation method with 20 segments. The outcome of the calibration and validation models was evaluated based on the values of the RMSEP, bias corrected RMSEP (SEP), as well as the determination coefficient (R^2), as these values in particular represent the proportion of the explained variance for the

Table 2. Calibration and prediction statistics for two modeling techniques for total anthocyanin models (TAC) based on the window 1000–2500 nm using different preprocessing options, for açai (*Euterpe oleracea* Mart.) and juçara (*Euterpe edulis* Mart.) populations described in Table 1.

Calibration								Prediction						
Population	n	SD	Modeling	Preprocessing	PC	R^2_{CV}	RMSECV	Population	n	SD	R^2_p	RMSEP	Bias	SDR _p ^z
Global (Açai+ Juçara)	294	17.5	PLSR	nil	14	0.70	9.58	Global (Açai+ Juçara)	74	18.84	0.84	7.69	-1.26	2.5
				SNV + DT	12	0.68	9.87				0.82	7.95	-1.16	2.4
				D1A (5 + 5)	9	0.70	9.62				0.82	7.86	-0.13	2.4
			PCR	nil	20	0.70	9.62				0.85	7.61	-1.08	2.4
				SNV + DT	20	0.68	9.86				0.81	8.09	-1.27	2.3
				D1A (5 + 5)	18	0.65	9.88				0.80	8.26	-0.68	2.3
Açai	134	7.65	PLSR	nil	10	0.68	4.35	Açai	34	7.08	0.72	3.76	0.63	1.9
				SNV + DT	18	0.72	4.01				0.74	3.56	0.83	2.0
				D1A (5 + 5)	12	0.65	4.49				0.72	3.68	0.25	1.9
			PCR	nil	10	0.48	5.57				0.53	4.91	-0.30	1.4
				SNV + DT	20	0.59	4.89				0.60	4.41	-0.40	1.6
				D1A (5 + 5)	12	0.57	5.06				0.55	4.96	-1.24	1.4
Juçara	160	20.5	PLSR	nil	13	0.61	12.85	Juçara	40	18.35	0.66	10.84	-2.12	1.7
				SNV + DT	9	0.62	12.74				0.65	10.62	-2.37	1.7
				D1A (5 + 5)	8	0.62	12.70				0.73	6.59	-1.49	1.9
			PCR	nil	18	0.63	12.50				0.68	10.50	-2.08	1.8
				SNV + DT	17	0.62	12.68				0.68	10.57	-2.56	1.8
				D1A (5 + 5)	8	0.55	13.87				0.62	11.44	-2.05	1.8

DT = de-trend; PC = principal component; PCR = principal component regression; PLSR = partial least square regression; RMSEP = root mean standard error of prediction; SEP = bias corrected RMSEP; SNV = standard normal variate.

^zRatio of the standard deviation of TAC to bias corrected RMSEP (SEP).

Fig. 2. Predicted vs. reference values of total anthocyanin (cyanidin-3-glucoside g·kg⁻¹ w/w) from partial least squares (PLSs) global model (—) using raw spectra in the near infrared region (NIR) of açai and juçara fruit, using only açai (---) and juçara (···) fruit.

Fig. 3. Predicted vs. reference values of total anthocyanin (cyanidin-3-glucoside $\text{g}\cdot\text{kg}^{-1}$ w/w) from partial least squares (PLSs) açai model using standard normal variate (SNV) + De-trend preprocessing spectra in the near infrared region (NIR) for the açai fruit.

response variable in the calibration and prediction group, and also the Ratio of Performance to Deviation (RPD) value (Golic and Walsh, 2006; Nicolaï et al., 2007).

Univariate analysis. The TA concentration data of the species (açai and juçara) and populations (calibration and prediction sets) underwent analysis of variance (ANOVA), adopting a completely randomized design (CRD), using the SAS computational system (SAS Institute, 1999) (Table 1).

Results and Discussion

Concentration of total anthocyanin. The TA content, expressed as cyanidin-3-glucoside ($\text{g}\cdot\text{kg}^{-1}$ w/w), was very similar across the two harvests (2010 and 2011). In 2010 harvest the TA values ranged from 0.3 to $80.4 \text{ g}\cdot\text{kg}^{-1}$, and in 2011 from $0.5 \text{ g}\cdot\text{kg}^{-1}$ to $75.0 \text{ g}\cdot\text{kg}^{-1}$ (Table 1). Moreover, the average values observed in 2010 were $10.4 \text{ g}\cdot\text{kg}^{-1}$ and $33.2 \text{ g}\cdot\text{kg}^{-1}$ in the açai and juçara fruits, respectively, and $12.0 \text{ g}\cdot\text{kg}^{-1}$ in the açai and $25.5 \text{ g}\cdot\text{kg}^{-1}$ in the juçara fruits in the 2011 harvest (Table 1). The juçara fruits exhibited two to three times more TA than the açai fruits in both harvests (Table 1), which confirmed previous reports from Iaderoza et al. (1992) and Rufino et al. (2010), who observed higher levels of this pigment in juçara fruits than in açai.

The observed differences might be associated with senescence, because during this phase of the fruit development, the vegetable tissues undergo changes in color as a result of

modifications to the contents and proportions of pigments (Tucker, 1993; Wills et al., 1998). In the case of açai and juçara palms fruits, the chlorophyll was degraded and a deep purple color appears, characterizing the ripe fruit (Iaderoza et al., 1992). However, even though the fruits have a purple color at the time of harvest, the lower levels of TA at the beginning of the harvest could be related to other factors, such as temperature, which, among other factors, affects the biosynthesis of these compounds. According to Yamane et al. (2006), the purple color of grapes is not as intense at high temperatures, and the accumulation of anthocyanin is inhibited at temperatures above 30°C . If this were the case for the açai and juçara fruits, higher summer temperatures (at the beginning of the harvest) could lead these fruits to have less of these compounds than those collected in autumn to winter (at the middle and at the end of the harvest season).

Original spectra and pre-processing. FT-NIR raw spectra of açai and juçara fruits (Fig. 1) were characterized with a source of error found in quantitative determinations involving NIR, which is light scattering (Mello, 1988), and the preprocessing techniques were used with the goal of mitigating the influence of variations in signal intensity. These transformations have also been used to determine the anthocyanin in grapes (Damberg et al., 2006) and to determine the nutraceutical compounds, including anthocyanin, in blueberries

(*Vaccinium corymbosum* L.) (Sinelli et al., 2008), which resulted in good prediction models. After preprocessing the NIR spectra signals, they were used to obtain the models, using PLSs and PCR.

Global model: açai and juçara. Although many preprocessing techniques were applied to NIR spectra, the best global model was obtained using PLS with raw spectra without removing any outliers (Table 2). This model had 14 latent variables (VLs), RMSEP of $7.7 \text{ g}\cdot\text{kg}^{-1}$, R^2 of 0.84 and RPD of 2.5 (Table 2). Although the PLS model results were similar to PCR models (RMSEP of $7.6 \text{ g}\cdot\text{kg}^{-1}$, R^2 of 0.85 and RPD of 2.4), the number of VLs observed in PCR models were much higher (20) than in PLS models, what makes PCR model more complex (Table 2). In this regard, only the PLS models will be further discussed.

Inácio et al. (2013) developed PLS models for TA prediction of açai and juçara fruits reporting a RMSEP of $4.8 \text{ g}\cdot\text{kg}^{-1}$ and R^2 of 0.90, but elliptical joint confidence region (EJCR) was used to detect outliers. As we did not remove any outliers, it might explain the differences in the results.

The RMSEP value found in the Global PLS model was over the range of TA-level determined in açai fruits ($10.4 \text{ g}\cdot\text{kg}^{-1}$ in year 2010, and $12.0 \text{ g}\cdot\text{kg}^{-1}$ in year 2011), Table 1. It can be explained in function to the higher absorbance of juçara than açai fruits (Fig. 2). It might have happened because juçara fruits are smaller and have thinner pericarp than açai fruits, and juçara

Fig. 4. Predicted vs. reference values of total anthocyanin (cyanidin-3-glucoside $\text{g}\cdot\text{kg}^{-1}$ w/w) from partial least squares (PLSs) juçara model using first derivative of Savitzky–Golay preprocessed spectra in the near infrared region (NIR) for the juçara fruit.

fruits also have less wax covering the pericarp (Calvi and Pina-Rodrigues, 2005; Pessoa and Teixeira, 2012). These differences can be perceived with the use of external diffuse reflection (Nicolai et al., 2007).

Because of the difference between açaí and juçara fruits and to reduce the RMSEP for each species, separate PLS models for açaí (Fig. 3) and juçara fruits (Fig. 4) were developed.

PLSs regression: açaí model. By using only the açaí fruits FT-NIR spectra the model was more adequate to the TA levels determined in açaí fruit, mainly because of the lower errors obtained with the açaí PLS model (Fig. 3).

Good calibration models were obtained using with spectra preprocessed with SNV + De-trend (Table 2). This model was more adequate to the TA levels determined in the açaí fruits, because the RMSEP value of $3.5 \text{ g}\cdot\text{kg}^{-1}$ was lower than the standard deviation for the average TA found in 2010 ($10.4 \pm 6.2 \text{ g}\cdot\text{kg}^{-1}$) and in 2011 ($12.0 \pm 8.3 \text{ g}\cdot\text{kg}^{-1}$), (Table 1). The açaí PLS model had 18 VLs, RMSEP of $3.6 \text{ g}\cdot\text{kg}^{-1}$, R^2 of 0.74 and RPD of 2.0 (Table 2). Although the coefficient of determination can be considered good, the RPD value of 2.0 means that the model can discriminate only low from high values of the response variable (TA), Nicolai et al. (2007). However, the simple separation of açaí fruits into high and low TA can help the industry to sort fruits and produce two category of pulp, one with ultra-high and other with high antioxidant activity, because the açaí market is linked with the high antioxidant activity of

this fruit, which is related to anthocyanin content (Lichtenthäler et al., 2005).

PLSs regression: juçara model. The best juçara PLS model was obtained with FT-NIR spectra preprocessed with the first derivative of Savitzky–Golay (Table 2). The PLS model developed exclusively with juçara fruits had 8 VLs, RMSEP of $6.6 \text{ g}\cdot\text{kg}^{-1}$, R^2 of 0.73, and RPD of 1.9 (Table 2).

The higher RMSEP values observed in the juçara PLS model (Fig. 3) must be influencing the errors observed in the Global PLS model (Fig. 2), making it impossible to use the Global model to predict TA content in açaí fruits. On the hand, the prediction of TA in juçara fruit can be done either by using the Global PLS model and the juçara PLS model, with the juçara model presenting the advantage of having fewer VLs than the Global model, what makes the juçara PLS model simpler (Table 2).

According to Damberg et al. (2006), the RPD value has been used as an indicator of the model robustness and gives an indication of how the prediction error related to the natural spread of the data. On the basis of this criterion, the juçara PLS model performed as well as açaí PLS model once the RPD values were similar, 1.9 and 2.0, respectively (Table 2).

The anatomical differences between açaí and juçara fruits were already mentioned as a factor that might affect the model performance, but the anthocyanin chemistry could also contribute as it results in spectral alterations (Damberg et al., 2006). The main anthocyanin in juçara fruit are cyanidin-3-glucoside and

cyanidin-3-rutinoside (Brito et al., 2007). Açaí also possess both anthocyanins, but Bobbio et al. (2000) reported that cyanidin-3-arabinoside and cyanidin-3-arabinosilarabinoside as the predominant compounds in açaí fruits. These differences support the development of separate models for açaí and juçara fruits.

Conclusion

NIR spectroscopy has proven to be a promising and nondestructive method to quantify TA content in the intact fruits of açaí and juçara palms. The individual PLS models of each species, mainly those obtained with external validation involving a test set, can be used with relative success to determine the levels of total anthocyanin. However, the global PLS model could be used for both species once the RMSEP are reduced. We need new studies that include data gathered from fruit from different producing regions, from distinct locations, and harvests over the whole course (harvest) of the season in their model so as to improve their robustness. This is the second attempt to report results that uses NIR spectroscopy to determine TA in intact açaí and juçara fruits as a nondestructive technology with promising use in grading lines.

Literature Cited

- A.O.A.C. 2006. Official methods of analysis of the Association of Official Analytical Chemists- met. 2005-02. 1st ed. Patricia, Arlington, TX.

- Alves, R.E., H.A.C. Filgueiras, J.L. Mosca, S.M. Silva, and J.B. Menezes. 2008. Postharvest physiology and biochemistry of some non-traditional American tropical fruits. *Acta Hort.* 768:233–238.
- Barnes, R.J., M.S. Dhanoa, and S.J. Lister. 1989. Standard normal variate transformation and detrending of near-infrared diffuse reflectance spectra. *Appl. Spectrosc. Rev.* 43:772–777.
- Barnes, R.J., M.S. Dhanoa, and S.J. Lister. 1993. Correction to the description of standard normal variate (SNV) and De-Trend (DT) transformation in practical spectroscopy with applications in food and beverage analysis. *J. Near Infrared Spec.* 1:1865–1886.
- Bellincontro, A., A. Taticchi, M. Servili, S. Esposito, D. Farinelli, and F. Mencarelli. 2012. Feasible application of a portable NIR-AOTF toll for on-field prediction of phenolic compounds during the ripening of olives for oil production. *J. Agr. Food Chem.* 60:2665–2673.
- Bobbio, F.O., J.I. Druzian, P.A. Abrão, P.A. Bobbio, and S. Fadelli. 2000. Identificação e quantificação das antocianinas do fruto do açazeiro (*Euterpe oleracea*) Mart. *Ciência Tecnol. Alim.* 20:388–390.
- Brito, E.S., M.C.P. Araújo, R.E. Alves, C. Carkeet, B.A. Clevidence, and J.A. Novotny. 2007. Anthocyanins present in selected tropical fruits: Acerola, Jambolão, Jussara, and Guajiru. *J. Agr. Food Chem.* 23:9389–9394.
- Calvi, G.P. and F.C. Pina-Rodrigues. 2005. Fenologia e produção de sementes de *Euterpe edulis*-Mart. Em trecho de floresta de altitude no município de Miguel Pereira-RJ. *Rev. Univ. Rural Sér. Ci. Vida.* 25:33–40.
- Damberg, R.G., D. Cozzolino, W.U. Cynkar, L. Janik, and M. Gishen. 2006. The determination of red grape quality parameters using the LOCAL algorithm. *J. Near Infrared Spec.* 14:71–79.
- Gallori, S., A.R. Bilia, M.C. Bergonzi, W.L.R. Barbosa, and F.F. Vincieri. 2004. Polyphenolic constituents of fruit pulp of *Euterpe oleracea* Mart. (açai plam). *Chromatographia* 59:739–743.
- Gishen, M., R.G. Damberg, and D. Cozzolino. 2005. Grape and wine analysis - enhancing the power of spectroscopy with chemometrics. *Austral. J. Grape Wine Res.* 11:296–305.
- Golic, M. and K.B. Walsh. 2006. Robustness of calibration models based on near infrared spectroscopy for the in-line grading of stone-fruit for total soluble solids content. *Anal. Chim. Acta* 555:286–291.
- Iadaroza, M., I.S.D. Baldini, and M.L.A. Bovi. 1992. Anthocyanins from fruits of açai (*Euterpe oleracea*, Mart) and juçara (*Euterpe edulis*, Mart). *Trop. Sci.* 32:41–46.
- Inácio, M.R.C., K.M.G. Lima, V.G. Lopes, J.D.C. Pessoa, and G.H.A. Teixeira. 2013. Total anthocyanin content determination in intact açai (*Euterpe oleracea* Mart.) and palmitero-juçara (*Euterpe edulis* Mart.) fruit using Near Infrared Spectroscopy (NIR) and multivariate calibration. *Food Chem.* 136:1160–1164.
- Kennard, R.W. and L.A. Stone. 1969. Computer aided design of experiments. *Technometrics* 11:137–148.
- Lichtenthäler, R., R.B. Rodrigues, J.G.S. Maia, M. Papagiannopoulos, H. Fabricius, and F. Marx. 2005. Total oxidant scavenging capacities of *Euterpe oleracea* Mart. (açai) fruit. *Intl. J. Food Sci. Nutr.* 56:53–64.
- Mello, C.A. 1988. Redes neurais e técnicas de pré-processamento de sinais em espectroscopia de reflectância no infravermelho próximo. Instituto de Química, Universidade Estadual de Campinas, Campinas, Dr. Thesis.
- Merzlyak, M.N., A.E. Solovchenko, and A.A. Gitelson. 2003. Reflectance spectral features and non-destructive estimation of chlorophyll, carotenoid and anthocyanin content in apple fruit. *Postharvest Biol. Technol.* 27:197–211.
- Naes, T., T. Isaksson, T. Fearn, and T. Davies. 2002. A User-friendly guide to multivariate calibration and classification. NIR Publication, MD.
- Nazarov, I., R.L. Wample, O. Kaye, A.O. Santos, and K. Goulart. 2005. Information and technology for sustainable fruit and vegetable productions frutic, “Near infrared laboratory on shoulder” Portable NIR solution. Montpellier, France.
- Nicolaï, B.M., K. Beullens, E. Bobelyn, A. Peirs, W. Saeys, K.I. Theron, and J. Lammertyn. 2007. Nondestructive measurements of fruit and vegetable quality by means of NIR spectroscopy: A review. *Postharvest Biol. Technol.* 46:99–118.
- Pacheco-Palencia, L.A., P. Hawken, and S.T. Talcott. 2007. Phytochemical, antioxidant and pigment stability of açai (*Euterpe oleracea* Mart.) as affected by clarification, ascorbic acid fortification and storage. *Food Res. Intl.* 40:620–628.
- Pasquini, C. 2003. Near infrared spectroscopy: Fundamentals, practical aspects and analytical applications. *J. Brazilian Chemist. Soc.* 14:198–219.
- Peirs, A., J. Tirry, B. Verlinden, P. Darius, and B.M. Nicolaï. 2002. Effect of biological variability on the robustness of NIR-models for soluble solids content of apples. *Postharvest Biol. Technol.* 28:269–280.
- Pessoa, J.D.C. and G.H.A. Teixeira. 2012. Tecnologias para inovação nas cadeias Euterpe. 1st ed. Embrapa, Brasília.
- Pozo-Insfran, D., C.H. Brenes, and S.T. Talcott. 2004. Phytochemical composition and pigment stability of açai (*Euterpe oleracea* Mart.). *J. Agr. Food Chem.* 52:1539–1545.
- Rogez, H. 2000. Açai: Preparo, composição e melhoramento da conservação. EDUFPA, Belém, PA.
- Rufino, M.S.M., R.E. Alves, E.S. Brito, J. Pérez-Jiménez, F. Saura-Calixto, and J. Mancini Filho. 2010. Bioactive compounds and antioxidant capacities of 18 nontraditional tropical fruits from Brazil. *Food Chem.* 121:996–1002.
- SAS Institute. 1999. SAS/STAT user's guide. 8th ed. SAS Institute Inc., Cary, NC.
- Savitzky, A. and M.J.E. Golay. 1964. Smoothing and differentiation by simplified least squares procedures. *Anal. Chem.* 36:1627–1632.
- Schauss, A.G., X. Wu, R.L. Prior, B. Ou, D. Huang, J. Owens, A. Agarwal, G.S. Jensen, A.N. Hart, and E. Shanbrom. 2006. Antioxidant capacity and other bioactivities of the freeze-dried amazonian palm berry, *Euterpe oleracea* Mart. (Acai). *J. Agr. Food Chem.* 54:8604–8610.
- Sinelli, N., A. Spinardi, V. Di Egidio, I. Mignani, and E. Casiraghi. 2008. Evaluation of quality and nutraceutical content of blueberries (*Vaccinium corymbosum* L.) by near and mid-infrared spectroscopy. *Postharvest Biol. Technol.* 50:31–36.
- Tucker, G.A. 1993. Biochemistry of fruit ripening. Chapman e Hall, Cambridge, U.K.
- Wills, R., B. Mcglasson, D. Graham, and D. Joyce. 1998. Postharvest: An introduction to the physiology & handling of fruit, vegetables & ornamentals. UNSW Press, Sydney, Australia.
- Yamane, T., S.T. Jeong, N. Goto-Yamamoto, Y. Koshita, and S. Kobayashi. 2006. Effects of temperature on anthocyanin biosynthesis in grape berry skins. *Amer. J. Enol. Viticult.* 57:54–59.
- Zude, M., M. Pflanz, K. Dosche, L. Spinelli, and A. Torricelli. 2011. Non-destructive analysis of anthocyanins in cherries by means of LambertBeer and multivariate regression based on spectroscopy and scatter correction using time-resolved analysis. *J. Food Eng.* 103:68–75.