Kinetic Modeling of Anthocyanin Degradation and Microorganism Growth during Postharvest Storage of Açai Fruits (*Euterpe oleracea*)

Hervé Rogez, Santuscha N. L. T. Akwie, Fábio G. Moura, and Yvan Larondelle

Abstract: The unavoidable damage of açai (*Euterpe oleracea*) fruits (AF) during picking leads to microbial contamination and anthocyanin degradation, which prejudice the consumed fruit drink. Thirteen lots of AF (24 kg) from different municipal districts of the Pará State (Brazil) were monitored during a 75-h-long storage in the dark at 30 °C for microbial growth, and 7 lots for anthocyanin degradation. On arrival at the laboratory, anthocyanins presented a mean concentration of 828 mg kg^{-1} fruits with a standard deviation of 323 mg kg^{-1} fruits whereas mean microbial contamination was 2.64 10^6 CFU g^{-1} of dry matter for total mesophilic bacteria, 1.98 10^3 MPN g^{-1} DM for fecal coliforms, and 1.11 10^5 CFU g^{-1} DM for moulds and yeasts. Kinetic growth of the microbes could be fitted to a quadratic equation with an unusual rapid growth during the 1st 24 h. The kinetics of anthocyanin degradation fitted a 1st-order equation. The mean velocity constant of the reaction (k_1) was of 0.0137 h^{-1} and the mean half-life ($t_{\frac{1}{2}}$) of the anthocyanins was 50 h. These results indicate that the AF simultaneously suffer extensive anthocyanin degradation and explosive microbial growth during the postharvest period needing a special care.

Keywords: anthocyanins, bacteria, fungi, kinetics

Practical Application: The data presented in this article help the industrial sector of açai (*Euterpe oleracea*) juice to understand: (1) the rapid kinetics of anthocyanin oxidation and (2) the uncommon kinetics of microorganism growth during a postharvest storage of açai fruits for up to 75 h. Our results allow to predict the global deterioration of açai fruits and pointed out the necessity of blanching the fruits or pasteurizing the juice.

Introduction

The açai palm tree (*Euterpe oleracea* Martius) is widespread in the Amazon floodplains (*varzea*) and is one of the most productive tree in this ecosystem. It produces açai fruits (AF), which grow in racemes, all year long, but at a higher rate between July and December (high season) than during the rest of the year (low season). The tree is also simultaneously exploited for its appreciated palm heart, which is largely exported from the State of Pará (Brazil). By contrast, the fruits are extensively marketed at the regional level in the form of a popular drink called "açai." The "açai" drink is elaborated through a step of fruit softening in water followed by trituration in a juice extractor in the presence of water. This leads to the production of a fatty emulsion. The final dry matter (DM) changes according to the proportion of water added during the process. The Brazilian açai classification of the emulsion has 3 categories: poorly viscous (8% to 11% DM), half viscous (11% to 14% DM), and viscous (>14% DM) (Brasil 2000; Bichara and Rogez 2011).

In the past 10 y, an economic boom was verified in the commercialization of this tropical drink, not only on the Brazilian market, but also at the international level (USA, Japan, and Europe) (Sabbe and others 2009; Pompeu and others 2009a).

The AF has a globular, round shape, with a diameter of 1 to 2 cm and a weight of 0.8 to 2.3 g. It is composed of core and pulp. The fruit pulp represents 5% to 15% of the fruit's volume, varying according to the origin and maturity of the fruit (Rogez and others 2011). During picking, AF suffer a rupture at their apex (Figure 1), allowing the entry of microorganisms and oxygen. In addition, AF do not have a thick exocarp as an effective defense mechanism and can be easily damaged during handling and transportation. The AF are usually put in baskets of 12 to 35 kg and transported by boat for 4 to 35 h until arrival at the local processing markets. Most of these baskets are made from the stalks of regional plants (*Desmoncus polyacanthus* or *Ischinasiphon obliquus*) and are used over 4 to 6 mo, without any hygienic treatment. The baskets are placed in direct contact with the contaminated surfaces such as the boat storage areas, the deck floor, and the ground of the market places. In the marketing chain of AF, the level of microbiological contamination of the different surfaces directly affects the sanitary quality of the fruit (Rogez 2000; Bichara and Rogez 2011). The high ambient temperature (approximately 30 °C) and relative humidity (approximately 90%) of the Amazon basin favor the growth of fungi and bacteria. As a result, the açai drink prepared in the traditional shops of the Amazonian cities is heavily contaminated. High levels of total mesophilic bacteria

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(TMB; from 4.1 10^4 up to 1.5 10^9 CFU/mL) and moulds and yeasts (from 2.3 10^4 to 8.3 10^6 CFU/mL) have been reported (Rogez 2000; Pompeu and others 2009b). Interestingly, Pompeu and others (2009b) showed that reducing the storage temperature of the fruits from 30 °C (ambient temperature) to 15, 10, or 5 °C led to a significant reduction (0.7 to 1.5 logarithmic order) of the TMB.

The damage caused to the fruits through picking and handling promotes enzymatic degradation, mainly through the activity of polyphenoloxidase that can be easily followed by anthocyanin disappearance. AF indeed contain a considerable amount of anthocyanins and are therefore classified as superfruits (Rogez and others 2011). Anthocyanins are a widespread source of antioxidants and are considered as a major quality factor for red fruit juices and red wines. They are also widely used as colorants in the food industry (Gould and others 2009). The major anthocyanins present in AF are cyanidin-3-rutinoside and cyanidin-3-glycoside (Gallori and others 2004; Pacheco-Palencia and others 2009). Pompeu and others (2009a) showed that the solvent-based extracts of phenolic compounds and anthocyanins can reach 4300 mg gallic acid equivalents/kg of fruits and 2500 mg anthocyanins/kg of fruits, respectively.

The loss of pigments is usually well described by kinetic models of zero order or 1st order (Smith 1981). Anthocyanin loss is considered to follow 1st order degradation kinetics (Patras and others 2010). Thermal stability of anthocyanins has been studied in different food matrices such as pomegranate (Martí and others 2001), grape (Morais and others 2002), strawberry (García-Viguera and others 1999), blackberry (Wang and Xu 2007), acerola (De Rosso and Mercadante 2007a), and even juice blends (De Rosso and Mercadante 2007b). Anthocyanins exposed to light in pomerac (*Syzygium malaccense*) led to photo-degradation because of the light stimulation of peroxidase activity (Sankat and others 2000). Accordingly, concord grapes and red cabbage loose anthocyanins when exposed to light, but with different kinetics, which may be explained by the high variability in the acylation and substitution in the anthocyanidin structure (Baublist and others 1994).

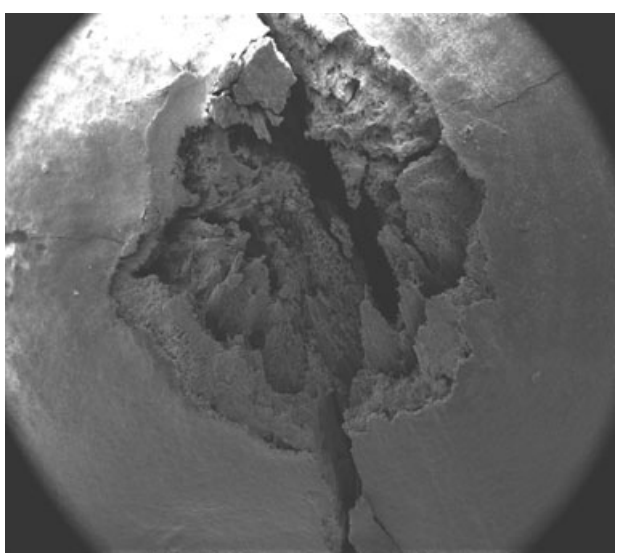

Figure 1–Damaged apex of an açai (*Euterpe oleracea*) fruit after picking (scale: 1:10).

Considering that the quality of the AF, both in terms of microbial load and anthocyanin content, has a major impact on the quality and acceptability of the natural açai drink, we designed a study aiming at describing the kinetics of anthocyanin oxidation and microbial growth during a postharvest storage of AF for up to 75 h and providing important data for this food sector.

Materials and Methods

Reagents

Standards used for quantification purposes were cyanidin-3-rutinoside and cyanidin-3-glucoside, purchased from Extrasynthèse (Genay, France). Buffer solutions were prepared using potassium chloride, hydrochloric acid, citric acid and sodium acetate, all of analytical grade, and obtained from Merck (São Paulo, Brazil). The reagents for the microbiological analyses were lauryl sulfate broth, EC broth, plate count agar, potato dextrose agar and brilliant green bile broth 2%; all were purchased from Isofar (Rio de Janeiro, Brazil). Deionized water was used throughout the study.

Material and experimental set-up

Thirteen lots of AF (each weighing 24 kg of fruits) were sorted within the area of Belém-Brazil allowing to study 3 independent factors: 1. The origin of the fruits (8 localities were sorted: Cumbu, Outeiro, Ourém, Ponta de Pedras, Marajó, Ilha das Onças, Redenção, and Abaetetuba); 2. The intrinsic variability for a same locality (2 lots were collected in Abaetetuba, and 3 lots in Cumbu and Ilha das Onças); 3. The production season (6 lots were sorted during the high production season (Ilha das Onças 1, Ilha das Onças 2, Abaetetuba 1, Cumbu 1, Cumbu 2 and Cumbu 3) and 7 during the low production season (Marajó, Redenção, Outeiro, Ourém, Ilha das Onças 3, Abaetetuba 2, and Ponta de Pedras)). All 13 lots were used for postharvest microbial follow-up. Seven of them (Outeiro, Abaetetuba 1, Abaetetuba 2, Ourém, Ponta de Pedras, Cumbu 1, and Cumbu 2) were also used for the anthocyanin follow-up. The maturity class of the 13 lots of fruits varies from stage 4 to 7 according to Rogez and others (2011). The soluble solids, pH, and titratable acidity (citric acid) were 9.9 ± 2.1%, 5.14 ± 0.09, and 0.11 ± 0.01%, respectively. The indices of maturity of 13 lots of fruits did not change significantly ($P < 0.05$) during the experiment. Two kg of AF were taken from each lot at regular intervals, during a 75-h-long storage period in the laboratory. Açai drinks were prepared from these samples and immediately subjected to both microbiological and anthocyanin analyses.

Collection and storage of fruit lots

The fruits were harvested by the plantation owners and transported in baskets to the AF market of Belém. They were then transferred to the laboratory. The time between the fruit harvest and the 1st açai sampling ranged from 2.5 h (Outeiro) to 24 h (Redenção). After arrival in the laboratory, the fruits were kept in the original containers (baskets) and stored in the dark for 75 h at 30 ± 1 °C (local conditions).

Preparation of the drink

Each fruit sample was washed 3 times with water and softened in 2 liters of water at 45 °C for 60 min. The fruits were then drained and the açai drink was prepared by means of a 4.5-min-long mechanical trituration of the fruits in a juice extractor (Figure 2). One liter of water was poured into the extractor during

the process on a regular and continuous way (Bichara and Rogez 2011). The equipment was washed and sterilized before and after each preparation.

Measurement of anthocyanin content

The quantification of anthocyanins was determined on the freshly prepared drink, using the pH differential method (Askar and Treptow 1993), optimized through the use of the balanced mean of molar weights (449.3 g/mol for cyanidin-3-glucoside and 595.5 g/mol for cyanidin-3-rutinoside) and the molar extinction coefficients (ε_{512} = 26441 M^{-1} cm^{-1} for cyanidin-3-glucoside and ε_{512} = 24386 M^{-1} cm^{-1} for cyanidin-3-rutinoside) of the major anthocyanins present in açai (cyanidin-3-rutinoside, 62.25% and cyanidin-3-glycoside, 37.75%) (Rogez 2000). A Biopharma 3001 spectrophotometer (Uppsala, Sweden) and 1 cm path length disposable cuvettes were used for absorbance measurements at 512 and 700 nm. The standards were diluted in solutions at pH = 1.0 (HCl in KCl 0.1 M) and pH = 4.5 (CH_3COOH, 0.1 M) at different concentrations and the linearity was respected in the absorbance range from 0.030 to 0.800 at both wavelengths. The specific absorbance was calculated with Eq. 1:

$$A = (A_{512} - A_{700})_{pH1.0} - (A_{512} - A_{700})_{pH4.5} \quad (1)$$

The concentration in anthocyanins was given by Eq. 2:

$$C\,(mg/kg\,fruits) = \frac{A \times MW \times DF \times 1000}{\varepsilon \times 1} \times \frac{[VA]}{[MAF]} \quad (2)$$

where C is the concentration of total anthocyanins (mg/kg of fruits), A is the specific absorbance, MW is the molecular weight (540.35 g/mol), DF is the dilution factor, 1000 is the conversion from g to mg, ε is the molar extinction coefficient (25245 M^{-1} cm^{-1}), 1 is the path length (cm), [VA] is the volume of açai drink (L), and [MAF] is the mass of AF (kg). Each result is the mean of 3 measurements made on the same açai drink and presenting a standard deviation below 12% of the mean. The results were expressed in DM to exclude the influence of 3 classifications of açai drinks.

Measurement of microbial contamination

The microbiological analyses were performed (TMB; moulds and yeasts; fecal coliforms) as described in the Compendium of Methods for the Microbiological Examination of Foods (Downes and Ito 2001). The results were also expressed on DM basis.

Kinetics and statistical analyses

The data on the anthocyanin content throughout the postharvest period are presented graphically as fitted with the Microsoft® Office Excel 7.0. For all data sets, the degradation kinetic model followed a 1st-order equation (Eq. 3):

$$C_t = C_0 \exp(-k_1 t) \quad (3)$$

where C_t and C_0 are the anthocyanin contents at time t and t_0, respectively, k_1 is the 1st-order kinetic constant, and t is the storage time (hours). A linear regression analysis ($-\ln(C/C_0)$ compared with time) was used to determine the adequacy of the anthocyanin degradation kinetic model. The half-life ($t_{\frac{1}{2}}$) of the anthocyanins content was calculated from Eq. 4:

$$t_{1/2} = \frac{\ln 2}{k_1} \quad (4)$$

The microbiological data were analyzed, using ANOVA, with the Software ECHIP 6.0 for Windows (ECHIP Inc., Hockessin, Germany). Differences with a confidence level higher than 95% ($P < 0.05$) were considered significant.

Results and Discussion

Kinetic modeling of anthocyanin degradation

A 1st determination of the anthocyanin content was performed on each lot upon arrival of the fruits in the laboratory. A great difference was observed between the initial values obtained. Indeed, the results varied between 334 and 1226 mg kg^{-1} fruits, with an average of 828 mg kg^{-1} fruits (Table 1). The large extent of anthocyanin concentrations may be explained, principally, by differences in fruit origin. Rogez and others (2011), studying AF from only 3 locations, have indeed reported that AF presented a maximum concentration of anthocyanins from 1159 to 1609 mg kg^{-1} fruits at the same maturity stage. Anthocyanin values of 879 mg kg^{-1} fruits were previously obtained in AF, when the same drink production process was performed (Pompeu and others 2009b), while values of 2500 mg kg^{-1} fruits were reached upon solvent extraction (Pompeu and others 2009a).

Anthocyanin degradation was monitored during the storage of fruits in the dark at 30 ± 1 °C. The analyses were performed on açai drink prepared at different storage times. The results were fitted to zero and 1st-order equations. The anthocyanin degradation were best fitted to the 1st-order equation (Figure 3), corresponding to an exponential equation ($C = 828 \cdot e^{-0.0137 \cdot t}$). The angular coefficient of the linear equation ($-\ln C/C_0 = k_1$ t) gave the

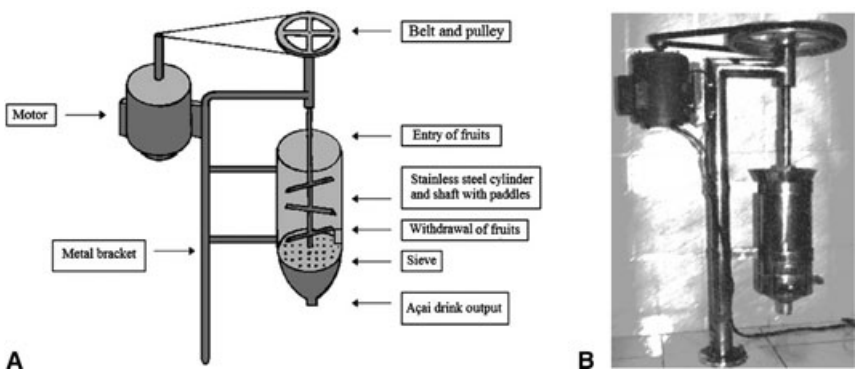

Figure 2–Juice extractor used to obtain the açai drink. Schematic components and path of the açai fruits (A) and real picture (B). Total height = 0.90 m, cylinder diameter = 0.18 m, cylinder height = 0.50 m. The inner shaft rotates at a speed between 240 and 380 rpm.

velocity constant (k_1), which varied from 0.0068 h^{-1} to 0.0226 h^{-1}, with a mean of 0.0137 h^{-1} and a SD of 0.0063 h^{-1} (Table 1).

The kinetics of anthocyanin degradation during AF storage was compared with the data found in the literature for sour cherry, red wine, and pure anthocyanins from blood orange (Table 1). For sour cherry, and red wine, for which no kinetics was reported, we adjusted the published values of anthocyanin degradation to 1st-order kinetics and analyzed their fit. All displayed 1st-order kinetics with an R^2 between 0.9411 and 0.9989. The mean result obtained for k_1 is in agreement with the value of 0.0120 h^{-1} reported by Pompeu and others (2009b) for AF of one specific origin (Outeiro). Sour cherry and grape wine presented higher and lower velocity constants than AF, respectively.

Table 1–Anthocyanin initial concentrations (C_0), degradation velocity constants (k_1), and half-life ($t_{\frac{1}{2}}$) during the storage of açai fruits (AF) of *Euterpe oleracea* in relation to their origin. Comparison with literature data available on AF, sour cherry, red wine, and pure anthocyanins from blood orange.

Fruit	C_0 (mg kg^{-1} fr)	k_1 (h^{-1})	$t_{\frac{1}{2}}$ (h)
AF-Abaetetuba 1	889	0.0226	30.67
AF-Abaetetuba 2	870	0.0068	101.93
AF-Cumbu 1	511	0.0183	37.88
AF-Cumbu 2	334	0.0075	92.42
AF-Ponta de Pedras	1226	0.0103	67.30
AF-Ourém	1167	0.0197	35.19
AF-Outeiro	800	0.0108	64.18
AF-mean	828	0.0137	50.59
AF-standard deviation	322	0.0063	26.54
Literature data			
AF-Outeiro^{+}	879	0.0120	57.76
sour cherry (T = 20 °C)$^{\#}$	65	0.0536	12.93
sour cherry (T = 30 °C)$^{\#}$	914	0.1232	5.62
grape model wine solution (pH = 4.5)^{o}	65.36*	0.0016	182.44
grape model wine solution (pH = 3.0)^{o}		0.0006	456.10
grape model wine solution (pH = 2.0)^{o}		0.0003	1038.03
Standard of cyanidin-3-glucoside (T = 70 °C)$^{\blacklozenge}$	6.9	0.0532	13.03
Standard of cyanidin-3-(6″-malonyl)glucoside (T = 70 °C)$^{\blacklozenge}$		0.0372	18.63

$^{+}$,$^{\#}$, ^{o}, and $^{\blacklozenge}$ experimental data from Pompeu and others (2009b), Petersen and Poll (1999), Romero and Bakker (1999), and Cao and others (2009), respectively. Note: * Total anthocyanins in mg/L.

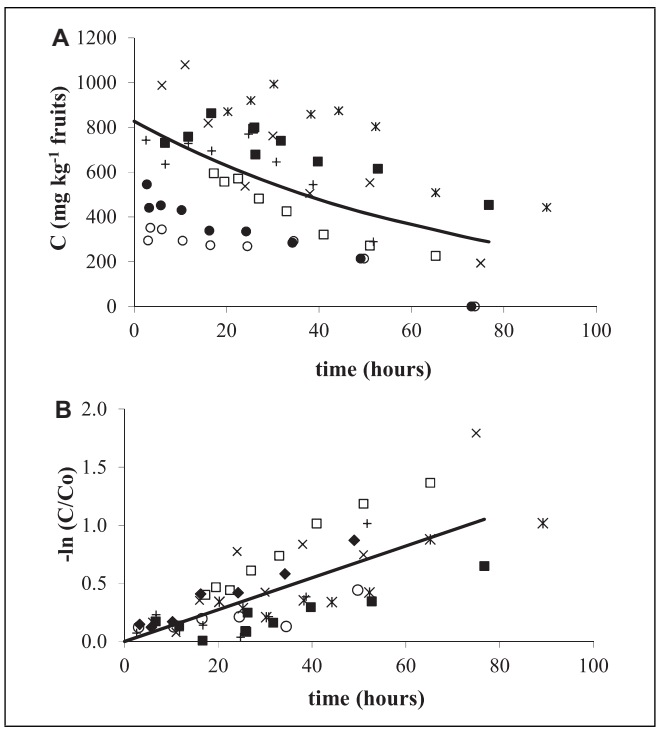

Figure 3–Changes in anthocyanin concentration (C), in 7 lots of *Euterpe oleracea* fruits during storage. The same data are presented before (A) and after (B) linearization. Full circles, Cumbu 1; open circles, Cumbu 2; full squares, Abaetetuba 2; open squares, Abaetetuba 1; stars, Ponta de Pedras; crosses, Ourém; plusses, Outeiro; full line, mean.

Half-life of the anthocyanins

As the transportation time from the field to the AF markets varies from 4 to 35 h, the half-life of the anthocyanin ($t_{\frac{1}{2}}$) is of major importance. A mean value of 50.59 h was obtained with a high SD of 26.54 h. The data of anthocyanin degradation in AF reported for Pompeu and others (2009b) show a value of 57.76 h for $t_{\frac{1}{2}}$, which fits within the results of the present study. The anthocyanins in AF are thus relatively sensitive and half of them have already been degraded within only 2.1 d after picking. This means that the açai drink is often prepared when a large portion (5% to 38%) of the anthocyanins is already degraded, leading to a loss for both the consumer and the industrial sector.

The half-life of anthocyanins is highly variable among fruits, wine, and pure anthocyanins (Table 1). The stability of anthocyanins in fruits is affected with several factors including temperature, pH, light, oxygen, and others (Patras and others 2010). The impact of temperature was clearly shown in sour cherry for which an increase in temperature from 20 °C to 30 °C reduced $t_{\frac{1}{2}}$ by more than 50%. The $t_{\frac{1}{2}}$ also depends on the pH value. Romero and Bakker (1999) demonstrated the influence of the pH on the degradation of total anthocyanins in a grape wine model solution. The results showed that a pH reduction from 4.5 to 2.0 increased the $t_{\frac{1}{2}}$ by 5.7 times. This observation was expected, since the anthocyanins are unstable at pH values higher than 3 (production of carbinol pseudo-base, quinoidal-base and chalcone) (Mazza and Miniati 1994). The $t_{\frac{1}{2}}$ of the anthocyanins also varies according to the species. Cao and others (2009) studied the thermal degradation of 2 anthocyanins at 70 °C and observed that cyanidin-3-glucoside was less stable than cyanidin-3-(6″-malonyl) glucoside, suggesting an increase in anthocyanin stability through acylation. Concerning the influence of light, De Rosso and Mercadante (2007b) evaluated the anthocyanin degradation in an isotonic soft drink system added to a crude extract of anthocyanins from açai pulp in the dark or when exposed the mixture to light. The results showed that anthocyanin stability was 3 times higher in the dark than in the presence of light (2 fluorescent white lamps of 32 W).

Kinetic modeling of microbial growth

Three groups of microorganisms (TMB, fecal coliforms and moulds and yeasts) were monitored during the postharvest storage of AF. Very significant growth was observed for each group. The statistical analysis of the data indicated that the kinetics of microbial growth during AF storage could be fitted to a quadratic equation ($a.t^2 + b.t + c$) with a rapid growth during the 1st 24 h. Table 2 gives the coefficients of the statistical analysis for each group of microorganisms. The negative value for the quadratic coefficient *a* indicates that growth is less rapid over time, suggesting progressive substrate exhaustion. The linear coefficient *b* was positive, indicating a general linear microbial growth.

TMB contamination of the açai drink prepared upon arrival of the fruits in the laboratory (initial value) presented a very high mean value of 2.64 10^6 CFU g^{-1} DM. AF from Redenção, Ilha

das Onças 3, and Marajó presented a higher initial contamination than the others. This is most likely linked to the relatively long time lapse between harvest and arrival in the laboratory for the fruits from Redenção (24 h), Ilha das Onças 3 (17 h), and Marajó (22 h). The bacterial contamination gained a 1st logarithmic order in 11.3 h after the start of the follow-up and a 2nd logarithmic order during the next 29 h with no significant difference between the 13 lots (Figure 4). Such a huge proliferation is not typically found in fruits but has been reported in chicken (Humphrey and others 1981). Factors like the nonacidic pH (mean of 5.23 ± 0.27), the wounds resulting from the picking (Figure 1) and handling, as well as the high local temperature and relative humidity, may explain these results (Bichara and Rogez 2011).

The mean contamination in fecal coliforms was initially of 1.98 10^3 MPN g^{-1} DM. This contamination most likely originated from the surfaces in contact with the fruits after picking, such as the baskets and the boat storage areas (Bichara and Rogez 2011). Fecal coliforms were observed to grow faster than TMB during storage: 1 and 2 logarithmic orders in 9.2 and 20.4 h, respectively (Figure 5). AF from Outeiro and Abaetetuba 2 respectively showed a significantly higher and lower contamination than the others.

The kinetic models illustrated in Figure 4 to 6 artificially suggest a decline in microbial contamination during the last part of the follow-up. In reality, this decline represents the stationary phase following the logarithmic growth phase.

The açai drink had a mean initial contamination in fungi (moulds and yeasts), of 1.11 10^5 CFU g^{-1} DM (Figure 6). The fungal contamination gained 1 and 2 logarithmic orders in 18 and 53 h of storage, respectively. This growth was predominately imputable to yeasts since moulds had a slower growth, as seen on the plates.

Taken together, the results of the present study show that the high microbial contamination of AF exceeded the mandatory limits fixed by the Brazilian Federal Legislation for açai drink (Brasil 2000). This contamination should be reduced by blanching the AF before açai drink preparation or by pasteurizing the drink before packaging. Rogez (2000) showed that pasteurization of the açai drink at 90 °C for 1 min at pH 3.75 reduced the TMB number by 6 logarithmic folds. Alexandre and others (2004) used the hurdle technology for açai preservation by the application of the following factors: reduction of pH to about 3.5, thermal treatment (82.5 °C for 1 min), reduction of water activity and addition of potassium sorbate (0.075% and 0.15% w/w). This

Table 2–Statistical results of the quadratic model expressing the changes in total mesophilic bacteria (TMB), fecal coliforms and moulds and yeasts during storage of açai fruits, as a function of time, fruit origin, and season.

Variable	Log TMB (g^{-1} DM)	Log fecal col. (g^{-1} DM)	Log moulds and yeasts (g^{-1}DM)
Constant#	8.1958	6.6168	7.1375
Time^{2o}	–0.0005*	·0.0010***	·0.0006**
Time (h)♠	0.0185*	0.0292**	0.0128*
Block [2]	NS		NS
Block [3]	0.3693**		0.4753***
Season [2]	·0.2283**		·0.3181***
Cumbu	NS		NS
Outeiro	NS	NS	NS
Ourém	0.3088*	0.9801***	NS
Ponta de Pedras	0.2608***	–1.395***	NS
Marajó	0.5332**		NS
Ilha das Onças	NS		NS
Redenção	NS		·0.1361*
Abaetetuba	NS	NS	NS
Time × Cumbu	NS		NS
Time × Outeiro	NS	NS	NS
Time × Ourém	NS	NS	NS
Time × P. de Pedras	NS	NS	NS
Time × Marajó	NS		NS
Time × Ilha das Onças	NS		NS
Time × Redenção	NS		NS
Time × Abaetetuba	NS	0.042***	NS
Time^2 × Cumbu	NS		NS
Time^2 × Outeiro	NS	–0.001*	NS
Time^2 × Ourém	NS	NS	NS
Time^2 × P. de Pedras	NS	0.0009*	NS
Time^2 × Marajó	NS		NS
Time^2 × Ilha das Onças	NS		NS
Time^2 × Redenção	NS		NS
Time^2 × Abaetetuba	NS	0.0007*	NS

Total experimental sets = 104; # constant given by ECHIP is the global mean at mean time; °,♠ refer to coefficients a and b in the quadratic equation $a.t^2 + b.t + c$; *, **, *** = Student test significant for $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively; NS = not significant; [block 2] and [block 3] = analysis of the factor block comparing different lots of fruits of the same origin in the high production season (Cumbu 1, Cumbu 2, and Cumbu 3); [season 2] = analysis of the factor block comparing 2 lots of fruits of the same origin but during different production seasons (Ilha das Onças 1 and 2 compared with Ilha das Onças 3).

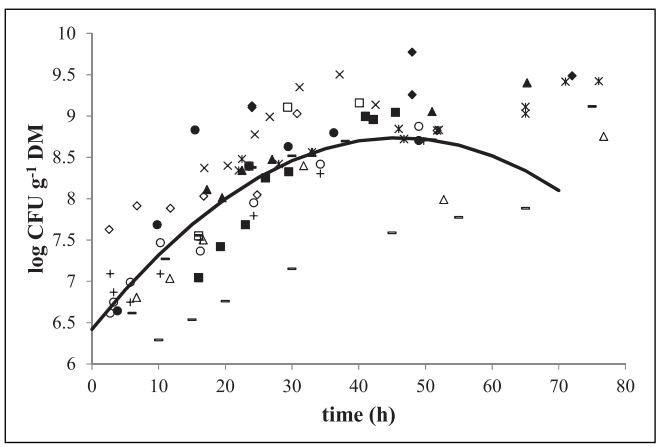

Figure 4–Kinetics of total mesophilic bacteria growth during storage of *Euterpe oleracea* fruits at 30 °C. Full circles, Cumbu 1; open circles, Cumbu 2; plusses, Cumbu 3; full squares, Ilha das Onças 1; open squares, Ilha das Onças 2; crosses, Ilha das Onças 3; full triangles, Abaetetuba 1; open triangles, Abaetetuba 2; full diamonds, Redenção; open diamonds, Outeiro; stars, Marajó; full trace, Ourém; open trace, Ponta de Pedras; line, mean.

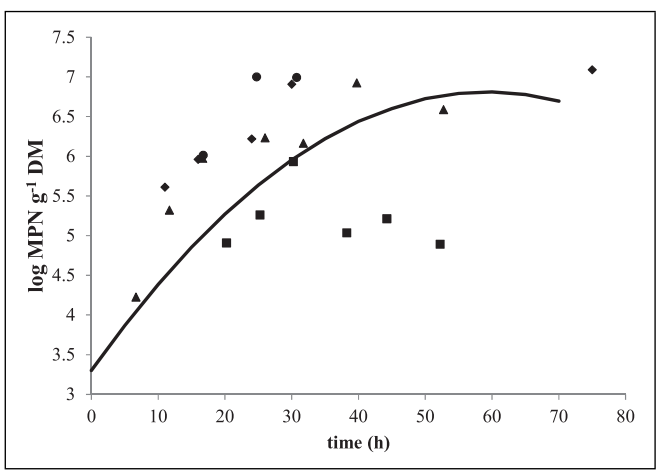

Figure 5–Kinetics of fecal coliform growth during storage of *Euterpe oleracea* fruits at 30 °C. Full circles, Outeiro; full squares, Ponta de Pedras; full triangles, Abaetetuba 1; full diamonds, Ourém; line, mean.

technology showed a good overall acceptability shelf-life of the açai drink during 5 mo. Sousa and others (2006) demonstrated the efficiency of a blanching of the AF (100 °C during 1 min), followed by a pasteurization of the drink (90 °C during 1 min), in eradicating microorganisms, while maintaining good sensory characteristics for 120 d of storage at −18 °C.

The global demand for açai drink has massively increased over the last decade. Bichara and Rogez (2011) commented on the worldwide importance of açai drink annual consumption that reached 240000 tons in Pará state, 58000 tons in the rest of Brazil, and 12000 tons abroad. Heinrich and others (2011) demonstrated that several manufacturing companies have aggressively marketed AF products in formulations such as energy drinks, powders, smoothies, and tablets, mostly in North America (mainly the United States), Europe, and Japan. Although açai has been one of the most highly praised nutraceuticals of the decade, there is insufficient and unconvincing scientific evidence to promote açai as an exceptional health supplement. Handling, harvesting, and transportation methods of AF are still very rustic. This is related to the resistance of açai growers in modern technologies, that is, pasteurization, clarification, and dehydration.

A new research topic regarding AF quality deals with the food-borne transmission of Chagas disease that is becoming recognized as increasingly important. Pereira and others (2012) have shown that during postharvesting, AF undergo spontaneous fermentation, with the production of lactic acid, acetic acid, ethanol, and CO_2. As the association of lactic acid and CO_2 leads to an increase in attractiveness for triatomines, and as outbreaks of Chagas disease have been associated with the açai drink, a sanitary management should be implemented all along the supply chain of AF.

Conclusions

The kinetic modeling of microorganism growth along a 75-h postharvest storage of 13 lots of AF was studied. The kinetic model for anthocyanins degradation was evaluated on 7 lots and followed a 1st-order kinetics. The mean value observed for anthocyanins was 828 mg kg^{-1} fruits. The half-life of the anthocyanins in AF is relatively long (50.59 ± 26.54 h) if compared to sour cherry. The kinetic growth of 3 groups of microorganisms (TMB, fecal coliforms and moulds and yeasts) fitted well to a 2nd-order equation. The initial values for TMB, fecal coliforms, and fungi exceeded the mandatory limits imposed by the Brazilian Federal Legislation. The rupture at the apex of the fruits during picking, the damage caused by handling and transportation, and the high temperature and relative humidity are thought to be the major causes of the rapid degradation of anthocyanins and of the highly explosive growth of the microorganisms in the AF. A sanitary management should be implemented all along the supply chain of AF (harvest, handling, transportation, and distribution). It would most likely participate to an efficient conservation of the açai drink, if associated to optimized preservation technologies (bleaching and/or pasteurization).

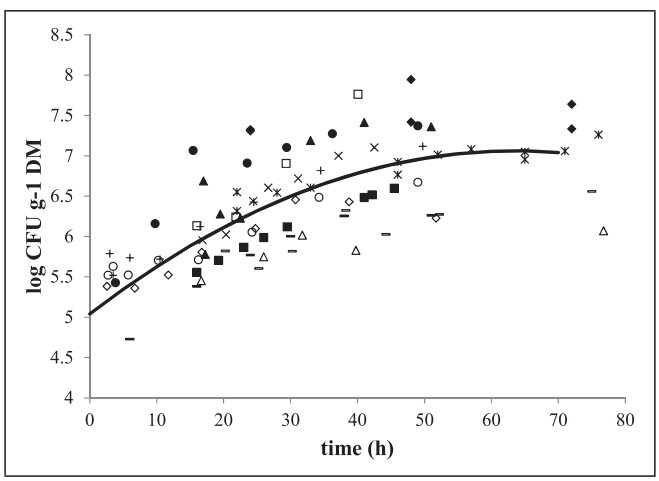

Figure 6–Kinetics of mould and yeast growth during storage of *Euterpe oleracea* fruits at 30 °C. Full circles, Cumbu 1; open circles, Cumbu 2; plusses, Cumbu 3; full squares, Ilha das Onças 1; open squares, Ilha das Onças 2; crosses, Ilha das Onças 3; full triangles, Abaetetuba 1; open triangles, Abaetetuba 2; full diamonds, Redenção; open diamonds, Outeiro; stars, Marajó; full trace, Ourém; open trace, Ponta de Pedras; line, mean.

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