Estimated shelf life of pupunha and tucumã flours

Estimativa do tempo de vida de prateleira de farinhas de pupunha e de tucumã

Vida útil estimada de harinas de pupunha y tucumã

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ABSTRACT
This study aimed to estimate the shelf life of pupunha (*Bactris gasipaes* Kunth) and tucumã (*Astrocaryum vulgare* Mart.) flours from family farming in northeastern Pará state, Brazil, by monitoring their physicochemical characteristics using the Accelerated Shelf-Life Test (ASLT) methodology. The pupunha and tucumã flours were subjected to controlled temperature (25, 35, and 45 °C) and humidity (80%) conditions. Moisture content (MC), water activity (Aw), total color difference (ΔE), and total carotenoid content (TC) were determined monthly over a period of 91 days. The pupunha and tucumã flours

showed respective MC values of 9.86 ± 0.12% and 4.86 ± 0.15%; Aw values of 0.59 and 0.33; and TC values of 104.95 ± 4.78 and 346.45 ± 16.67 µg of β-carotene/g (dry-weight basis). The ΔE data indicate a significant increase between 33 and 61 days, with values greater than 5. Moisture remained within legal limits, while the other parameters varied significantly. Only the Aw and TC data fit the kinetic regression models, following zero-order and first-order kinetics, respectively. According to the models, water activity is the first parameter to impact the stability of the flours, exhibiting the lowest activation energy (*Ea*) values, whereas TC is more influenced by temperature increases, showing higher *Ea* values. It is estimated, therefore, that pupunha and tucumã flours can maintain their functional appeal as a source of carotenoids for approximately 172 and 287 days, respectively, when stored at 25 °C and 80% humidity.

Keywords: *Bactris gasipaes* Kunth. *Astrocaryum vulgare* Mart. Shelf Life. Bragantina Network of Solidarity Economy, Arts, and Flavors. Quirera Network.

RESUMO

Este estudo buscou estimar o tempo de vida de prateleira de farinhas de pupunha (*Bactris gasipaes* Kunth) e de tucumã (*Astrocaryum vulgare* Mart.), da agricultura familiar do nordeste paraense, por meio do monitoramento de características físico-químicas, empregando-se a metodologia de Teste Acelerado de Vida-de-Prateleira (ASLT). As farinhas de pupunha e de tucumã foram submetidas a condições controladas de temperatura (25, 35 e 45 °C) e umidade (80%). Os parâmetros umidade (MC), atividade de água (Aw), variação de cor (ΔE) e carotenoides totais (TC), foram determinados mensalmente durante o período de 91 dias. As farinhas de pupunha e de tucumã apresentaram, respectivamente, MC de 9,86 ± 0,12 % e 4,86 ± 0,15 %, Aw de 0,59 e 0,33 e TC de 104,95 ± 4,78 e 346,45 ± 16,67 □g□□-caroteno/g (base seca). Os dados de (ΔE), indicam uma significativa elevação entre 33 e 61 dias, com valores maiores que 5. A umidade manteve-se dentro dos limites legais, e os demais parâmetros variaram significativamente. Apenas os dados dos parâmetros de Aw e TC se ajustaram aos modelos cinéticos de regressão, de zero e primeira ordem, respectivamente. De acordo com os modelos, o parâmetro que primeiro impacta a estabilidade das farinhas é a atividade de água, com os menores valores de energias de ativação (*Ea*), enquanto TC é mais influenciado pelo aumento de temperatura, com maiores valores de *Ea*. Estima-se, assim, que as farinhas de pupunha e tucumã têm condições de manter seu apelo funcional, como fonte de carotenoides, por cerca de 172 e 287 dias, respectivamente, quando armazenadas à 25 °C e 80% de umidade.

Palavras-chave: *Bactris gasipaes* Kunth. *Astrocaryum vulgare* Mart. Vida-de-prateleira. Rede Bragantina de Economia Solidária Artes e Sabores. Rede Quirera.

RESUMEN

Este estudio tuvo como objetivo estimar la vida útil de las harinas de pupunha (*Bactris gasipaes* Kunth) y tucumã (*Astrocaryum vulgare* Mart.), provenientes de la agricultura familiar del noreste de Pará, Brasil, mediante el monitoreo de sus características fisicoquímicas, utilizando la metodología de Prueba de Vida Útil Acelerada (ASLT). Las harinas de pupunha y tucumã fueron sometidas a condiciones controladas de temperatura (25, 35 y 45 °C) y humedad (80%). Los parámetros humedad (MC), actividad de agua (Aw), variación de color (ΔE) y carotenoides totales (TC) se determinaron mensualmente durante 91 días. Las harinas de pupunha y tucumã presentaron, respectivamente, MC de 9,86 ± 0,12% y 4,86 ± 0,15%, Aw de 0,59 y 0,33, y TC de 104,95 ± 4,78 y 346,45 ± 16,67 µg β-caroteno/g (base seca). Los datos de ΔE indican un aumento significativo entre los días 33 y 61, con valores superiores a 5. La humedad se mantuvo dentro de los límites legales, mientras que los demás parámetros variaron significativamente. Solo los datos de Aw y TC se ajustaron a los modelos de regresión cinética, de orden cero y primer orden, respectivamente. Según los modelos, el primer parámetro que impacta en la estabilidad de las harinas es la actividad de agua, con los valores de energía de activación (*Ea*) más bajos. En contraste, el TC es más influenciado por el aumento de la temperatura, con valores de *Ea* más altos. Por lo tanto, se estima que las harinas de pupunha y tucumã pueden mantener su atractivo funcional como fuente de carotenoides durante aproximadamente 172 y 287 días, respectivamente, cuando se almacenan a 25 °C y 80% de humedad.

Palabras clave: *Bactris gasipaes* Kunth. *Astrocaryum vulgare* Mart. Vida Útil. Rede Bragantina de Economia Solidária Artes e Sabores. Rede Quirera.

1 INTRODUCTION

The Quirera Network is a successful case of open innovation in which family farmers from northeastern Pará state, Brazil, who are members of the Bragantina Network of Solidarity Economy, Arts, and Flavors, collaborate with Embrapa Eastern Amazon to incrementally improve existing processes and products, such as edible vegetable flours, in pursuit of positive socioeconomic impacts. According to Fonseca and Silva (2024), socio-productive diversification must be conducted in a way that ensures the commercialization of surplus family production. One way to achieve this is by defining measurable verification criteria and/or quality control requirements for these products.

The initial demand from the Quirera Network focused on evaluating and continuously improving the processing of fruits such as pupunha (*Bactris gasipaes* Kunth) and tucumã (*Astrocaryum vulgare* Mart.) for food flour production. This practice is essential to reducing post-harvest losses of these species in their natural state, which occur due to storage capacity limitations. It is also a matter of food and nutritional sovereignty for producing families and their communities (Mendes; Gonçalves, 2023), ensuring the supply of products with a longer shelf life.

Pupunha and tucumã are fruits of Amazonian native species belonging to the Arecaceae family. The high bioavailable carotenoid content in the edible parts of both pupunha (β-carotene and lycopene) and tucumã (β-carotene and α-carotene) classifies them as foods of high nutritional quality (Neri-Numa *et al*., 2018; Abreu *et al*., 2020). Additionally, oil rich in polyunsaturated fatty acids (linoleic and linolenic) is also extracted from the edible parts of both. The high concentration of these bioactive compounds, along with fat-soluble vitamins and phenolic compounds, enhances the functional and economic value of these fruits in addition to their nutritional attributes (Ibiapina *et al*., 2022).

Shelf life is the period during which a product remains safe and suitable for consumption under defined storage conditions. This duration can be estimated by storing the product under high-stress conditions (such as elevated temperature and humidity) using the Accelerated Shelf-Life Test (ASLT) methodology (Haouet *et al*., 2018).

Therefore, the objective of this study was to estimate the shelf life of flours produced from the edible parts of pupunha and tucumã fruits at Embrapa Eastern Amazon by monitoring their physicochemical characteristics using the ASLT methodology.

2 METHODOLOGY

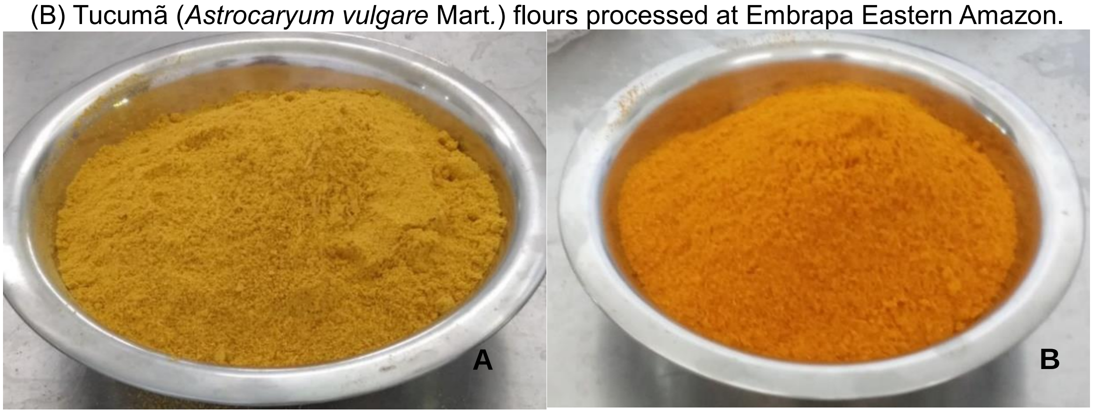
2.1 RAW MATERIAL SOURCING

Pupunha (*B. gasipaes*) and tucumã (*A. vulgare*) fruits, collected in July 2023 from municipalities in northeastern Pará state, were provided by remaining quilombo communities that are part of the Bragantina Network of Solidarity Economy, Arts, and Flavors.

2.2 FLOUR PROCESSING

Pupunha and tucumã flours (Figure 1) were obtained by processing the fruits in their natural state at Embrapa Eastern Amazon, following the methodology described by Carvalho *et al*. (2005).

Figure 1. (A) Pupunha (*Bactris gasipaes* Kunth) and
(B) Tucumã (*Astrocaryum vulgare* Mart.) flours processed at Embrapa Eastern Amazon.



Source: Personal collection.

2.3 SHELF-LIFE ESTIMATION

For shelf-life estimation experiments, samples of approximately 10 g of tucumã and pupunha flours were packaged in high-barrier laminated pouches (stand-up pouch, ziplock-Tradpouch), placed in an airtight container with a lid, and stored in BOD (Biochemical Oxygen Demand, Solab) incubators at temperatures of 25 °C, 35 °C, and 45 °C, with a relative humidity of 80 ± 1.50%, for 91 days, in triplicate. The ambient humidity of the storage container was saturated with water vapor by placing a polypropylene beaker containing 100 mL of distilled water inside, and humidity was measured using a data logger (TESTO, Model 175-H2).

Monthly evaluations of water activity (Aw), total color difference (ΔE), and total carotenoid content (TC) were performed in triplicate over 91 days. The data obtained were analyzed to determine the order of the alteration reaction, and the reaction rates (*k*) were calculated for each of the three temperatures.

The values of these parameters were plotted against storage time for each temperature, followed by linear regression. The slope obtained in the linear regression for each temperature corresponds to the *k* value (reaction rate).

The activation energy (*Ea*) values for each parameter were determined by constructing an Arrhenius plot, where Ln(*k*) was plotted against 1/T (K) for each temperature in Kelvin. The slope of the resulting line corresponds to *Ea*/R, where R is the ideal gas constant (R = 1.987 $cal \cdot gmol^{-1} \cdot K^{-1}$). An alternative way to express the dependence of alterations on temperature variations is the Q_{10} value, defined as the ratio between reaction rate constants at temperatures differing by 10 °C. This value represents the increase in shelf life resulting from a 10 °C temperature reduction (Azeredo, 2012).

The Q_{10} values were calculated using Equation 1:

$$Q_{10} = 10^{Ea/(0.46\,.\,T^2)} \tag{1}$$

where:

Ea is the activation energy in cal/mol and T is the temperature in Kelvin.

The shelf life (SL) was calculated using Equations 02 and 03, for zero- and first-order reactions, respectively:

$$SL\ (days) = (Ci - Cf)/k \tag{2}$$

$$SL\ (days) = Ln\ (Cf/Ci)/k \tag{3}$$

where:

C_i and C_f are the initial and final concentrations of the measured parameters, and *k* represents the reaction rate constants.

The end of shelf life was defined based on the threshold reached for each variable, according to technical quality references. The following limits were adopted: 0.70 for Aw, 32.4 µg/g for TC, and 5.0 for ΔE (Rojas-Garbanzo *et al*., 2016).

According to Rahman and Labuza (2007), the critical range for preventing microbial growth is between 0.60 and 0.70 of Aw. However, ANVISA legislation (Collegiate Board Resolution [RDC] 711/2022), which sets sanitary requirements for flours, only establishes a maximum moisture content of 15% for this type of product. This generally corresponds to Aw values above 0.75. Therefore, in this study, 0.70 was set as the limit value for defining the end of shelf life for the flours.

For a food product to be considered a source of carotenoids, it must provide at least 15% of the recommended dietary allowance (RDA) for vitamin A, as established in RDC 360/03 (Agência Nacional de Vigilância Sanitária, 2003). For calculation purposes, a RDA of 900 µg of RAE (retinol activity equivalent) was considered, knowing that 1 mg of RAE is equivalent to 12 mg of β-carotene, as per Normative Instruction 75/2020 (Agência Nacional de Vigilância Sanitária, 2020). The calculations were based on 50 g portions of flour, following RDC 429/2020 (Agência Nacional de Vigilância Sanitária, 2020). Thus, the shelf life of the flours was determined based on reaching the minimum threshold of 32.4 µg of total carotenoids per gram of flour.

2.4 PHYSICOCHEMICAL CHARACTERIZATION

Moisture content (MC) was determined using a reference gravimetric method, in triplicate, by directly desiccating the sample in an oven at 105 °C, following the protocol of the Adolfo Lutz Institute (2008).

Water activity in the flours was measured using a dew point analyzer (AQUALAB 4TE, Addium), in triplicate, according to the manufacturer's instructions. Each sample was homogenized, and portions were placed in three measuring capsules for individual readings.

The color parameters of the flours were evaluated using a DeltaVista spectrophotometer (Delta Color), following the manufacturer's instructions. The CIELAB color space method was applied to determine the following parameters: Lightness (L*), where L* = 0 corresponds to black and L* = 100 to white;

Chromaticity a*, indicating the transition from green (-a*) to red (+a*); and Chromaticity b*, indicating the transition from blue (-b*) to yellow (+b*) (Semighini, 2018).

The total color difference (ΔE), which must be equal to or greater than 5 to be perceptible between two samples (Rojas-Garbanzo *et al*., 2016), was calculated using Equation 4:

$$\Delta E = [(L^*_f - L^*_i)^2 + (a^*_f - a^*_i)^2 + (b^*_f - b^*_i)^2]^{1/2} \quad (4)$$

where:

L^*_f, a^*_f, b^*_f = values of readings at a given storage time; and L^*_i, a^*_i, b^*_i = initial values (t = day 0).

Total carotenoid (TC) content was determined using the method proposed by Rodriguez-Amaya (2001), with results expressed in β-carotene, in triplicate, using an Evolution 300 UV-Vis spectrophotometer (Thermo Scientific). Results were calculated on a dry-weight basis.

2.5 DATA ANALYSIS

The results for MC, TC, color parameters, and Aw were initially subjected to descriptive statistics and expressed as mean ± standard deviation. The moisture data were used to calculate total carotenoids on a dry-weight basis. To assess the dataset, Grubbs' test was applied to detect extreme values, while Ryan-Joiner's test (similar to Shapiro-Wilk) was used to evaluate normality. Levene's test was conducted to assess the homogeneity of variances. Differences between means were analyzed using analysis of variance (ANOVA), with Dunnett's test employed to compare each treatment against the single control. A significance level (p-value) of $p \leq 0.05$ was adopted for all statistical tests. The calculations were performed using Excel® 2010 (Microsoft, WA, USA) and Minitab® 19 (Minitab Statistical Software, PA, USA) software.

3 RESULTS AND DISCUSSION

The results of the flour shelf-life estimation study demonstrated a normal data distribution based on the Ryan-Joiner test and homoscedasticity according to Levene's test. Additionally, the absence of extreme values was confirmed using Grubbs' test, indicating that random variability is inherent to the data. Thus, the analysis performed using Dunnett's test was appropriate for evaluating differences between the mean values of the data and the control level mean (time = day 0), at a 5% probability level.

3.1 MOISTURE

According to the results presented in Table 1, the MC determined for pupunha and tucumã flours at day zero was 9.86 ± 0.12% and 4.85 ± 0.15%, respectively. Rojas-Garbanzo *et al*. (2012) reported a MC of 13% for pupunha flour, while Leite *et al*. (2022) found a value of 2.49% for tucumã flour.

Table 1. Moisture content (MC) of pupunha and tucumã flours during the shelf-life estimation study.

Temperature (°C)	25	35	45
Time (days)		**Pupunha flour**	
0	9.86 ± 0.12 A	9.86 ± 0.12 A	9.86 ± 0.12 A
33	10.44 ± 0.05 A	10.86 ± 0.07	11.67 ± 0.13
61	10.26 ± 0.24 A	11.02 ± 0.14	12.71 ± 0.04
91	11.12 ± 0.07	12.42 ± 0.05	14.42 ± 0.14
		Tucumã flour	
0	4.85 ± 0.15 A	4.85 ± 0.15 A	4.85 ± 0.15 A
33	5.80 ± 0.11	6.51 ± 0.08	7.41 ± 0.13
61	6.46 ± 0.26	7.26 ± 0.12	7.92 ± 0.06
91	7.48 ± 0.16	8.64 ± 0.18	9.34 ± 0.02

Means in the same column labeled with the letter A are not significantly different from the control level (time = day 0) by the Dunnett method at 95% confidence.
Source: Prepared by the authors.

The low MC of the flours facilitates storage and transportation, in addition to extending shelf life by hindering chemical and enzymatic reactions and inhibiting microbial growth (Prado *et al*., 2022).

Both flours showed significant variation in MC over 91 days of storage but remained within the maximum limit of 15% permitted by national legislation (Agência Nacional de Vigilância Sanitária, 2022).

Therefore, the drying and storage processes of the pupunha and tucumã flour samples were adequate to meet market standards and comply with current legislation regarding moisture content. However, despite being within the acceptable range, the initial MC of pupunha flour was twice that of tucumã flour. This difference may influence Aw and, consequently, the shelf life of the flours.

3.2 WATER ACTIVITY

Water activity is a key parameter for food stability, as it prevents or limits microbial growth, which has direct implications for food safety. High water activity increases perishability, as it provides a favorable environment for physicochemical reactions and microbial proliferation. Forsido *et al*. (2021) recommend low Aw values for flour storage.

For pupunha flour, a significant increase ($p \leq 0.05$) was observed in Aw values, from 0.59 (day 0) to 0.78 (45 °C/91 days) (Table 2).

Although a similar trend was observed for tucumã flour, with Aw values increasing over time from 0.33 (day 0) to 0.69 (45 °C/91 days), its initial Aw value was substantially lower than that of pupunha flour.

Table 2. Variation in water activity (Aw) of Pupunha and Tucumã flours during the shelf-life estimation study.

Temperature (°C)	25	35	45
Time (days)		**Pupunha flour**	
0	0.586 ± 0.007 A	0.586 ± 0.007	0.586 ± 0.007
33	0.606 ± 0.024 A	0.640 ± 0.024	0.657 ± 0.014
61	0.651 ± 0.006	0.682 ± 0.009	0.734 ± 0.004
91	0.687 ± 0.004	0.728 ± 0.010	0.778 ± 0.011
		Tucumã flour	
0	0.330 ± 0.004 A	0.330 ± 0.004	0.330 ± 0.004
33	0.424 ± 0.000	0.457 ± 0.005	0.510 ± 0.008
61	0.485 ± 0.009	0.544 ± 0.016	0.575 ± 0.015
91	0.590 ± 0.000	0.634 ± 0.002	0.689 ± 0.006

Means in the same column labeled with the letter A are not significantly different from the control level (time = day 0) by the Dunnett method at 95% confidence.
Source: Prepared by the authors.

3.3 COLOR CHANGE

The total color difference (ΔE) for pupunha flour ranged from 3.38 ± 0.69 (25 °C/33 days) to 35.37 ± 9.04 (35 °C/91 days), while for tucumã flour, it ranged from 1.03 ± 0.24 (25 °C/33 days) to 29.24 ± 0.29 (45 °C/91 days). Although at 25 °C after 33 days, the color difference was not perceptible to the human eye (ΔE < 5), a progressive increase in ΔE was observed over time. In other words, between 33 and 61 days at 25 °C, total color difference would become perceptible in both pupunha and tucumã flours, according to Rojas-Garbanzo *et al*. (2016). However, sensory analysis would be required to determine the actual impact on consumer acceptance. As shown in Table 3, particularly for pupunha flour, higher temperatures led to faster changes in total color difference.

Table 3. Variation of total color difference (DE) of pupunha and tucumã flours during the shelf-life estimation study.

Temperature (°C)	25	35	45
Time (days)		**Pupunha flour**	
0	0	0	0
33	3.38 ± 0.69	8.96 ± 1.02	16.15 ± 0.51
61	7.21 ± 0.49	13.01 ± 1.19	20.70 ± 0.91
91	31.34 ± 3.57	35.37 ± 9.04	31.84 ± 2.21
		Tucumã flour	
0	0	0	0
33	1.03 ± 0.24	8.34 ± 0.56	15.95 ± 0.89
61	5.61 ± 1.67	8.84 ± 0.99	21.64 ± 0.65
91	25.30 ± 0.77	12.32 ± 1.06	29.24 ± 0.29

Source: Prepared by the authors.

3.4 CAROTENOIDS

As shown in Table 4, a significant decrease ($p \leq 0.05$) in TC content was observed in both flours over storage time (33, 61, and 91 days) at all temperatures (25, 35, and 45 °C). Similarly, the effect of temperature was evident.

Table 4. Total carotenoid content (in mg b-carotene/g; dry-weight basis) in pupunha and tucumã flours during the shelf-life estimation study.

Temperature (°C)	25	35	45
Time (days)		**Pupunha flour**	
0	104.95 ± 4.78 A	104.95 ± 4.78	104.95 ± 4.78
33	79.74 ± 6.56	57.71 ± 0.52	27.96 ± 1.01
61	66.36 ± 4.80	43.00 ± 7.89	14.02 ± 1.49

91	53.36 ± 4.92	29.14 ± 3.62	7.54 ± 0.21
		Tucumã flour	
0	346.45 ± 16.67 A	346.45 ± 16.67	346.45 ± 16.67
33	263.00 ± 5.16	225.68 ± 1.76	148.80 ± 2.54
61	202.51 ± 6.44	166.32 ± 5.77	70.48 ± 6.13
91	154.68 ± 11.48	154.68 ± 11.48	37.53 ± 1.87

Means in the same column labeled with the letter A are not significantly different from the control level (time = day 0) by the Dunnett method at 95% confidence.

Source: Prepared by the authors.

The TC content in pupunha flour showed a reduction of nearly 14 times its initial value, while the variation observed in tucumã flour did not exceed 10 times its initial content.

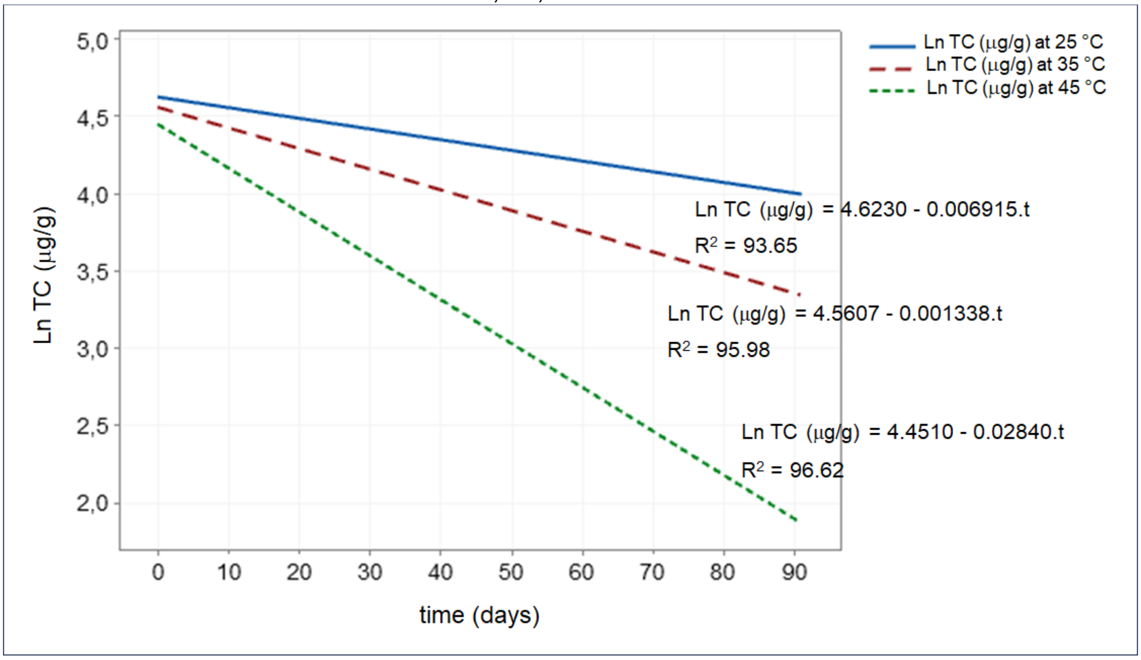
This decrease in TC content was likely due to degradation processes such as isomerization and oxidation, which commonly occur in foods subjected to heat treatments (Rodriguez-Amaya, 2001). These variations may also have contributed to color changes in the flours.

3.5 ESTIMATION OF SHELF LIFE

Based on the data presented, kinetic models were established for Aw and carotenoid content (exemplified in Figure 2), and the reaction orders along with their rate constants (*k*) were determined (Table 5). However, color variation data exhibited a lack of model fit, preventing the use of regression models to predict shelf life and construct the Arrhenius plot.

Water activity followed a zero-order model, whereas carotenoid content followed a first-order model. These findings align with Teixeira Neto *et al*. (1993), who stated that the main reactions in food, such as microbial growth and death, vitamin and pigment degradation, toxin formation, and enzymatic activity, typically follow first-order kinetics, meaning they depend on the concentration of their components. In contrast, zero-order reactions are independent of component concentrations and are common when there are diffusion limitations in the reaction process—such as the permeation of water vapor through the packaging wall.

Figure 2. Kinetic model of the total carotenoid content (TC) of pupunha flour during storage at 25, 35, and 45 °C.



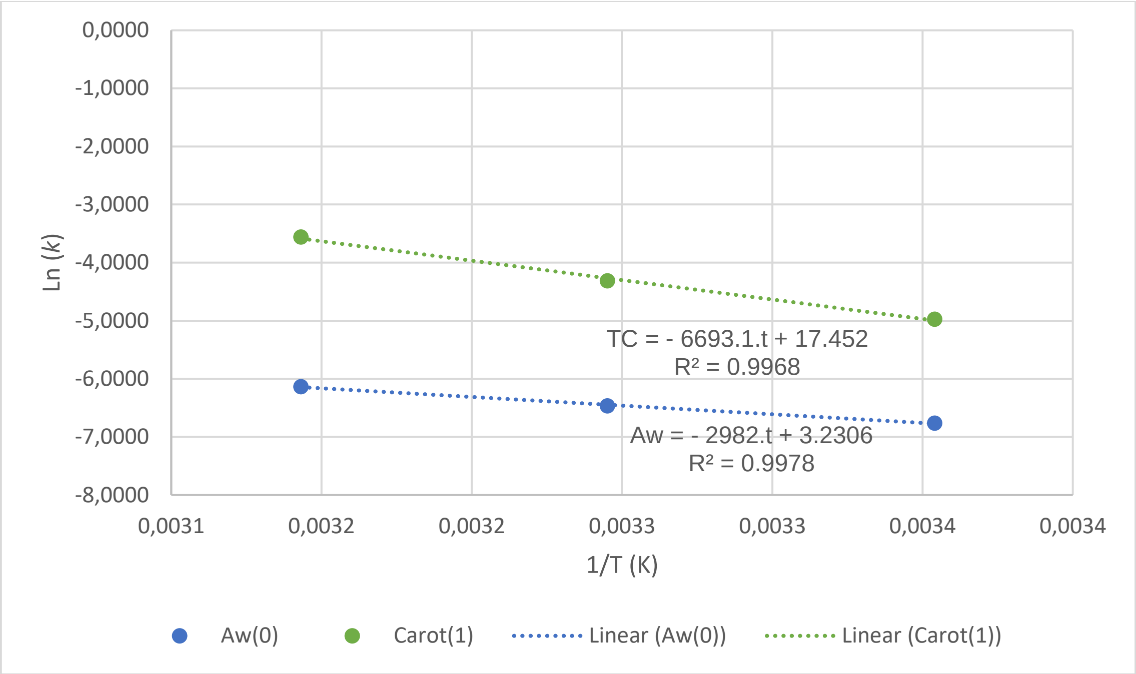
Source: Prepared by the authors.

Using the reaction rate constants, Arrhenius plots for Aw and carotenoid content (Figure 3) were constructed for both flours. From these, the *Ea* values were obtained, allowing the calculation of Q_{10} and the estimated shelf life at 25 °C (Table 5).

According to the *Ea* values, Aw is the first parameter to impact the stability of both flours, as it has the lowest *Ea*, meaning molecular activation begins at lower temperatures. In contrast, carotenoid content requires higher temperatures, exhibiting higher *Ea* values.

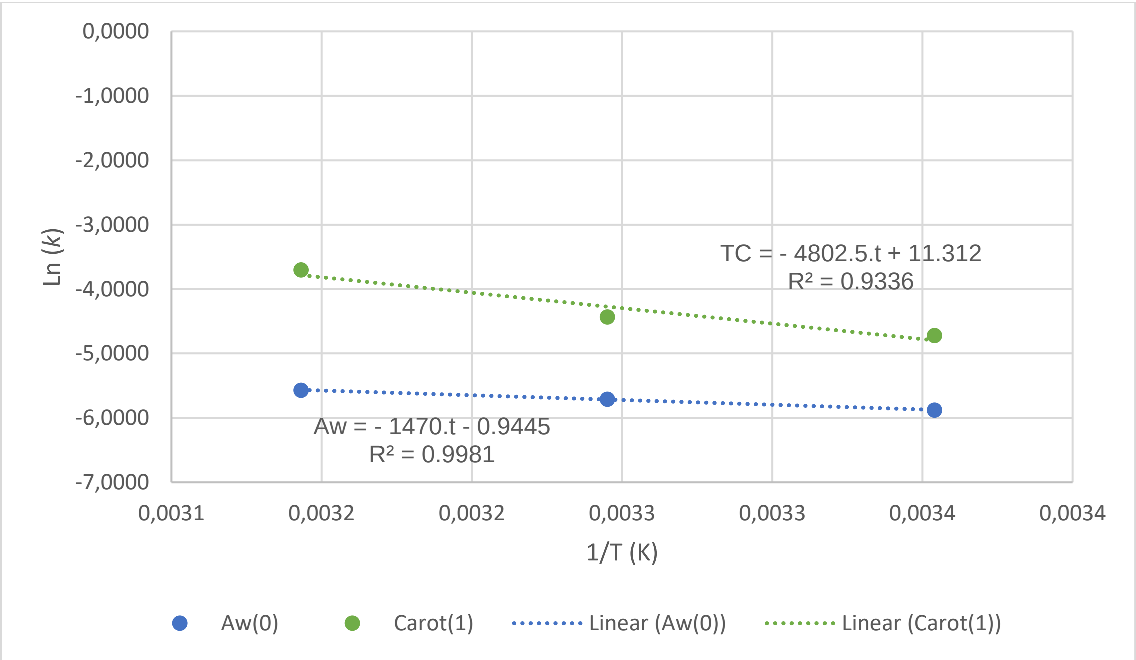
Although tucumã flour has a lower initial Aw, its reaction rate (*k*) is twice as high as that of pupunha flour, resulting in a shelf life only 35 days longer.

Figure 3. Arrhenius plots for water activity (Aw) and total carotenoid content (TC) in pupunha flour.



Source: Prepared by the authors.

Figure 4. Arrhenius plots for water activity (Aw) and total carotenoid content (TC) in tucumã flour.



Source: Prepared by the authors.

Table 5. Estimation of the shelf life of pupunha flour and tucumã flours regarding water activity (Aw) and total carotenoid content (TC).

Parameter	Order	k (10^{-3}/day)	*Ea* (Kcal/mol)	Q_{10}	SL 25 °C (days)
Aw Pupunha	0	1,15	5.93	1.40	96
TC Pupunha	1	6.76	13.30	2.11	174
Aw Tucumã	0	2.81	2.92	1.18	131
TC Tucumã	1	8.27	9.54	1.71	287

Source: Prepared by the authors.

Regarding Aw, pupunha and tucumã flours are estimated to be marketable for approximately three and four months, respectively, before reaching the critical Aw threshold (Aw = 0.7). This parameter can also be validated through microbial load analyses, considering that products with low initial contamination will be affected later by increasing Aw.

According to Vasques *et al*. (2006), the shelf life of a low-water-activity food primarily depends on the protection provided by its packaging, which serves to minimize or prevent moisture absorption from the storage environment.

When considering carotenoid degradation as the limiting factor, pupunha flour could be marketed for approximately six months, while tucumã flour could last nine and a half months.

The main selling point of pupunha and tucumã flours is the preservation of their carotenoid content. Despite significant variations in color and Aw, carotenoid levels remained within the required limits set by legislation for more than three months at 25 °C.

The shelf life of whole or partially sifted flours varies depending on their origin and degree of processing. Flours with lipid contents above 10% are stable for about three months, whereas refined flours with less than 10% lipids can last up to one year. The cold chain has been widely used to help preserve the properties of these types of products (Espinoza-Tellez *et al*., 2024).

4 CONCLUSION

The initial moisture content and, consequently, the water activity of the flours obtained by processing pupunha and tucumã fruits vary over time, potentially impacting shelf life. However, both parameters remain within legal limits.

Color changes and TC degradation in pupunha and tucumã flours increase over time and with temperature.

Water activity follows a zero-order reaction, whereas carotenoid degradation adheres to a first-order reaction mechanism.

Under marketing conditions of 25 °C and 80% humidity, the estimated shelf life of pupunha and tucumã flours is less than two months due to color changes; three and four months, respectively, based on water activity; and six and nine and a half months, respectively, considering carotenoid retention.

The use of pupunha and tucumã fruits can provide nutritional and income diversification for local populations and those involved in their processing. Just as the maintenance of nutrients during a storage period that exceeds the seasonal range of the species, it is a technological challenge that, when overcome, can contribute to their inclusion in other marketing sectors, in addition to human food.

Even with the good results obtained, studies to define shelf life require sample volume, which in this study was limited, since it involved artisanal products from biodiversity. In order to accurately define the shelf life of pupunha and tucumã flours, other complementary studies are still necessary, such as sensory analysis to assess consumer acceptance, especially in relation to color variation, and microbiological analysis to monitor compliance with regulations.

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