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Encapsulated omega-3 addition to a cashew apple/araça-boi juice - effect on sensorial acceptability and rheological properties

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Abstract

The elaboration of fruit blends added of functional components results in nutritionally enriched products. The purpose of this work was to evaluate the physicochemical, sensorial and rheological properties of cashew-apple and araça-boi beverages added with encapsulated omega-3 and stability during 120 days of storage. Juice formulations were prepared with and without adding omega-3 oil and encapsulated omega-3, pasteurized and stored at room temperature, and evaluated sensory, physicochemical and rheological properties. The optimized formulation of the beverage was obtained with 18.6% of cashew-apple and 9.3% of araça-boi pulps, selected in the experiment of the response surface. The formulations with encapsulated omega-3 maintained sensory acceptability. The physicochemical parameters did not present significant interactions among the formulations and the storage time. A consumer test with 100 people was performed using an acceptance test and check all that apply (CATA). The beverage added with unencapsulated omega-3 presented a variation in the sensory attributes along with the storage. All samples showed non-Newtonian behavior and pseudoplastic character. Omega-3 encapsulation is recommended to favor the acceptability and constancy of rheological characteristics in the beverage nutritionally enriched with omega-3.

Keywords: tropical fruit beverage; encapsulated omega-3; rheology.

Practical Application: Mixed beverages were prepared using the pulp of the cashew apple (*Anacardium occidentale L.*) and araça-boi pulp (*Eugenia stipitata*). The omega-3 encapsulation with cashew-tree gum is recommended to beverage enrichment. The omega-3 encapsulation avoid changes in the sensory acceptability and rheological behavior of the beverage. The rheological parameters did not change with the storage of the samples, for the 120 days of storage. It was feasible in practical application the edible encapsulation.

1 Introduction

The food industry is still struggling to offer new products to satisfy consumer needs. The growing demand for healthy products has challenged the food and beverage sector. The market for functional beverages represents the largest and fastest growing segment of the functional foods sector (Shahidi & Alasalvar, 2016). The fortification of beverages with omega-3 (ω-3) fatty acids, dietary fibre, minerals, and vitamins has grown tremendously (Shahidi & Ambigaipalan, 2016). There have been efforts among scientists and industries to explore and use different food sources and combinations of different elements to develop new products (Kraak et al., 2011).

Juice blends have been increasingly developed due to the industrial demand for diversified foods and their flavours. Several researches can be found regarding blend juices, as strawberry, apple and lemon (Feng et al., 2020), camu-camu and jabolan (Campos et al., 2021) and pineapple and mango (Shamsudin et al., 2020).

The araça-boi fruit (*Eugenia stipitata* McVaugh) presents an attractive and more tropical flavor and aroma. Its acidity limits its fresh consumption, but its pulp has excellent potential in the agricultural industry for manufacturing different products, like jams (Viana et al., 2012). It is rich in bioactive compounds and has a high content of antioxidant activity (Denardin et al., 2015; Nastur et al., 2016). Fruits that are not well known by the Brazilian population, such as araça-boi, allow innovations and new products that add commercial value and benefits to consumer health (Negri et al., 2016).

The cashew apple is a very nutrient rich fruit presenting in its composition: vitamins, polyphenols, sugars, minerals, amino acids and dietary fibre cashew apple, therefore providing an important nutritional source (Das & Arora, 2017). Considering its high nutritional value, it is an excellent prospect as a raw material for developing new drinks with exotic flavors.

Today, food does not seek only to satisfy hunger and provide the necessary nutrients for humans but also to prevent chronic diseases and improve one's well-being. High health care costs can explain the increased demand for such foods, increased life expectancy, and older people's desire to improve the quality of

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life (Betoret et al., 2011). Therefore, this has been studied in addition to functional compounds, aiming at developing a drink with beneficial health effects (Faraoni et al., 2013).

Among the functional components, polyunsaturated omega-3 fatty acids have been added to many food products such as ice cream (Ullah et al., 2017) and milk (Nagarajappa & Battula, 2017). The omega-3 has multiple effects on the health of the population. These effects lead to an improvement in blood pressure, heart function, and lipid metabolism. The omega-3 also has an anti-inflammatory effect; it reduces oxidative stress and assists in preventing various diseases, including cardiovascular disease, cancer, arthritis, and Alzheimer's disease (Mori, 2006; Dimitrow & Jawien, 2009). The beneficial effects of omega-3 have also been demonstrated to prevent type 2 diabetes, rheumatoid arthritis, and other diseases (Kris-Etherton et al., 2002; Yehuda et al., 2002). The introduction of lipid components, such as omega-3, often becomes difficult in some products because of difficult homogeneous dispersion in the medium. In general, omega-3 is difficult to disperse in food products. Moreover, polyunsaturated fatty acids are susceptible to auto-oxidation, which results in off-flavors and toxic compounds (Gharsallaoui et al., 2007). Therefore, additional processing steps such as encapsulation may be used. Encapsulation is a technology that can meet the challenge of successfully incorporating and delivering functional ingredients, like omega-3, preventing its oxidative deterioration and off-flavor (Ruiz & Campos, 2016).

Omega-3 encapsulation using different matrix is already being researched for this purpose (Venugopalan et al., 2021; Vieira et al., 2021), in need of more studies on food application of these encapsulates and its difference with the inclusion of uncapsulated omega-3.

Polysaccharides generally may be suitable for obtaining nanoparticles, mainly due to their physicochemical properties, low cost, availability, and biodegradable characteristics. One of the main advantages of using polysaccharides as components for the synthesis of nanoparticles is their natural molecular recognition since they have specific receptors in individual cells (Liu et al., 2008). Because it is a polysaccharide exudate of Brazilian trees, mainly native to the Northeast, cashew gum has been studied, presenting a high possibility of commercial production for use as encapsulate matrix.

This study aimed to analyze the physicochemical, sensory evaluation and rheological behavior of mixed cashew and araça-boi drinks with added omega-3 (encapsulated and uncapsulated) during 120 days of storage.

2 Material and methods

2.1 Formulations and fruit pulp proportions

Mixed beverages were prepared using cashew apple (*A. occidentale* L.) pulp, provided by a fruit pulp industry in Fortaleza (Brazil), and araça-boi pulp (*E. stipitate* McVaugh) was collected at the Fazenda Ouro Verde (Green Gold Farm), located in Vila Brazil - Bahia State. The polyunsaturated fatty acid omega-3 was obtained from seaweed origin (*Schizochytrium* sp), furnished by a local juice industry.

To define the composition of the mixed beverages, eleven formulations were prepared (nine formulations and three repetitions of the central point) using different proportions of cashew apple and araça-boi pulps through the response surface. For beverages preparation, after weighing, the pulps were homogeneized with water and commercial sucrose. The formulations were prepared and pasteurized at 90°C in an Armfield FT74 tubular UHT/HTST heat exchanger and followed by a hot filling in 210 mL glass bottles previously sterilized and closed with plastic caps. The bottles were then cooled (water at 10 °C) and stored at room temperature until sensory analysis.

The study used a Central Composite Design (CCD) with four assays at the α levels +1 and -1; four assays at the level of axial points (α = -1.414 and +1.414) and three repetitions in the central point (α = 0), totaling eleven assays performed in a random sequence (Barros et al., 1995). The proportions of fruit pulp varied from 1:3 to 3:1 (araça-boi to cashew apple, w:w), with 10 to 30% of pulp mixture and the soluble solids standardized to 11 °Brix with the addition of sucrose (Table 1).

To optimize the formulation by higher sensory acceptance, these eleven trials were evaluated by 48 untrained panelists (Stone & Sidel, 1993) in laboratory tests through the delineation of complete balanced blocks (MacFie et al., 1989) of potential consumers.

2.2 Beverage processing and effect of ômega-3 addition

Based on the chosen formulation and to evaluate the impact of omega-3 addition to the beverage, three different treatments were processed: F1 (control beverage), F2 (beverage added with omega-3), and F3 (beverage added with an omega-3 encapsulated with cashew tree gum). In two of the formulated beverages, the omega-3 was added in accordance with the Brazilian legislation for foods with functional property claims (0.1 g - docosahexenoic acid- DHA in 100 mL of the product to be consumed). Three repetitions of the formulations (F1, F2 and F3) were prepared and pasteurized at 90 °C in an Armfield FT74 tubular UHT/HTST heat exchanger and followed by a hot filling in 210 mL glass bottles

Table 1. Rotational Central Composite Design (CCD), with four trials at +1 and -1 levels, 4 trials at axial point levels (-1.414 and +1.414), and three repetitions at the central point (0). The fruit pulp content was from 10 to 30%, and the proportion (araçá-boi: cashew apple) from 1: 3 to 3: 1 (w:w) according to the pulp percentage in the mixture.

Trial	Pulp proportion (araçá-boi: cashew apple)	Pulp amount (%) (cashew apple + araçá-boi)	Overall acceptance
1	0.72	12.91 (7.5 + 5.41)	6.7
2	2.61	12.91 (3.57 + 9.33)	7.5
3	0.72	27.09 (15.74 + 11.35)	7.1
4	2.61	27.09 (7.5 + 19.60)	6.3
5	0.33	20.00 (15.0 + 5.0)	7.2
6	3.00	20.00 (5.0 + 15.0)	6.3
7	1.67	10.00 (3.75 + 6.25)	6.8
8	1.67	30.00 (11.25 + 18.75)	6.1
9 (C)	1.67	20.00 (7.5 + 12.5)	5.1
10 (C)	1.67	20.00 (7.5 + 12.5)	5.8
11 (C)	1.67	20.00 (7.5 + 12.5)	5.2

previously sterilized and closed with plastic caps. The bottles were then cooled (water at 10 ºC) and stored at room temperature (25 ± 2 ºC) for 120 days. In the F3 formulation, the omega-3 used was encapsulated using cashew-gum, as described below.

2.3 Encapsulation of omega-3 with cashew gum and particle characterization

Cashew gum was obtained from the exudate of cashew tree and purified following the methodology described by Rodrigues et al. (1993) with some modifications, being ground, mixed in water (1:10 w:v ratio) to extract the gum, filtered. Then the gum was precipitated by ethanol (1:4 w:v ratio). The gum was washed twice with ethanol, under vacuum filtration, to remove possible traces of fats or other impurities. Information about the cashew gum characterization can be found in Ribeiro et al. (2016).

Capsules were made by forming a fine and stable emulsion of the core material (vegetable oil - DHA) within the wall solution (cashew gum 10% w:w). The ratio was 1:30 (w:w) in the relation nucleus: wall material. To improve the stability of the solution, it was added tween 20 as an emulsifying agent in the proportion 1:1 (nucleus: emulsifying agent, w:w). The dispersion was homogenized for two minutes at 14000 min^{-1} in a Turratec homogenizer (TECNAL model TE-102) and then freeze-dried.

Particle size was checked using a Zetasizer Nano model ZS 3600 particle size analyzer, Malvern. Analysis of polyunsaturated fatty acids in the oil and encapsulated oil samples (28) was performed by gas chromatography to verify the presence of 4,7,10,13,16,19-docosahexaenoic acid (DHA) in the synthesized particles.

2.4 Physicochemical analyses

Soluble solids were measured using a digital refractometer AR200 (Reichert, USA). The pH was measured using a pHmeter model HI9321 Hanna Instruments (Italy). Titratable acidity was determined by titrimetry using NaOH solution 0.1 M (Association of Official Analytical Chemists, 2005). Color was determined with a colorimeter (Minolta CR 400, Switzerland), with CIELAB parameters L* (lightness), a* (red-green), b* (yellow-blue) color space was applied to perform color measurements and Hue = $\tan^{-1}$ (b*/a*) e Croma = $(a^{*2} + b^{*2})^{1/2}$.

2.5 Sensory evaluation

The sensory evaluation was carried out with 100 untrained panelists, enlisted as suggest by Meilgaard et al. (2006). The test consisted of (i) acceptance tests for overall appearance, flavor, and overall acceptance, using nine-point structured hedonic scales (1: 'disliked extremely' to 9: 'liked extremely'); (ii) The panelists were asked to complete a questionnaire called Check-All-That-Apply (CATA) after the acceptance test. The CATA test had 22 descriptive terms related to the sensory and non-sensory characteristics of the beverages. The terms were selected according to preliminary tests made with possible panelists. The panelists were asked to "check" the terms that best describe the features for each beverage sample during testing. The frequency was determined by counting the number of panelists who used the same terms often, according to Vidal et al. (2015). The panelists received 30 mL of each sample in a monadic evaluation of each treatment in completely balanced blocks. The samples were refrigerated at 6 ± 2 C for 4 h before the evaluation and served at 9 ± 1 C. The research was submitted and approved by the Research Ethics Committee, through the Brazil platform, under number 52/12.

2.6 Rheological parameters

The rheological behavior of the mixed beverages was determined using a concentric cylinder rheometer (Brookfield Searle, model R/S SST Plus 2000, USA). Determinations were carried out at 25 °C provided by a thermostatic bath (Brookfield, model TC-502) connected to the equipment. Shear stress and shear rate were recorded using RHEO V2.8 software (Brookfield Co., USA). The rheological behavior was measured with a shear rate ranging from 0 to 500 s^{-1} (upward curve) and from 500 to 0 s^{-1} (downward curve) for 1 min with 25 readings for each curve. Readings were carried out in duplicate, and for each measurement, a new sample was used. The rheological behavior was determined according to the method described by Silva et al., 2012b.

2.7 Statistical analyses

The experimental design and statistical analyses of physicochemical and rheological parameters were performed using XLSTAT version 2021 (Addinsoft, 2021). For all analyses, determinations were made in triplicate as independent experiments. The components of variance for balanced split-plot experiments were determined, considering a complete factorial design with the first factor distributed in the formulations and a second factor in the subplots (five storage times: 0, 30, 60, 90 and 120 days). The data obtained in the physical-chemical and sensorial analyzes were submitted to analysis of the interaction between formulations and storage and regression times, and when appropriate, Tukey's test was performed to compare means at a 5% probability level.

The rheological data obtained from the analysis models were fitted to the Ostwald-de-Waelle, Casson, Herschel-Bulkley and Newton methods. The data was described in Equations 1, 2, 3 and 4, respectively, with the rheological parameters for each model determined, as well as their coefficients of determination (R^2)

$$\tau = K\left(\dot{\gamma}\right)^{n} \quad \text{(Ostwald-de-Waelle)} \tag{1}$$

$$\tau = \tau_0 + K_H\left(\dot{\gamma}\right)^{n_H} \quad \text{(Herschel-Bulkley)} \tag{2}$$

$$(\tau)^{0,5} = K_{OC} + \kappa_c(\gamma)^{0,5} \quad \text{(Casson)} \tag{3}$$

$$\tau = \eta\left(\dot{\gamma}\right) \quad \text{(Newton)} \tag{4}$$

Where: τ = shear stress (Pa), K = consistency index (Pa.s), n = flow behavior index (dimensionless), γ = shear rate (s^{-1}), K_{OC} = initial tension of Casson (Pa), K_C = viscosity of Casson ($Pa.s^n$).

Correspondence analysis (CA) was used to obtain a two-dimensional representation of the samples and the relationship between the samples and the terms of the CATA. This analysis was performed on the frequency table containing the samples in the columns and the attributes used by the consumers to describe the samples in the lines, using XLSTAT software for Windows version 2021.1 (Addinsoft, 2021).

3 Results and discussion

3.1 Formulations of the fruit beverages

The experiment results with different proportions of fruit pulp (cashew apple and araça-boi) evaluated in the CCD experiment are presented in Figure 1. It was possible to establish a response surface and the representative equation obtained to calculate the overall acceptance $(z) = 9.33 - 0.85\,x + 0.57\,x^2 - 0.23\,y + 0.007\,y^2 - 0.06\,x\,y$.

The optimized formulation with 27.9% of pulp amount and a 2:1proportion of araçá-boi:cashew-apple (corresponding to 9.3% araçá-boi pulp and 18.6% cashew apple pulp) presented the best acceptance score in the sensory evaluation. This proportion was chosen for the next experiment, with the addition of omega-3 and evaluation of stability during storage. The optimized beverage was prepared and split in the treatments as planned: F1 (control beverage), F2 (with omega-3 oil), and F3 (with encapsulated omega-3) pasteurized and prepared for storage and analyses. These formulations, soon after processing, presented 0.39 to 0.40 acidity (g of citric acid 100 g^{-1}), pH of 3.05, and 11.67 to 11.74% of soluble solids. The sensory acceptance score was 6.0 to 6.9, equivalent to "liked" on the hedonic scale.

3.2 Particles characterization of encapsulated omega-3

In the qualitative analysis of chromatography of the oil sample containing DHA and the encapsulated oil used in the beverages, it was possible to identify the expected fatty acid 4,7,10,13,16,19-docosahexaenoic (DHA) to provide the functionality to the beverage, with a retention time of 34 minutes. The average particle size of DHA (core) and cashew gum (wall material) particles was 144.1 ± 12.9 nm.

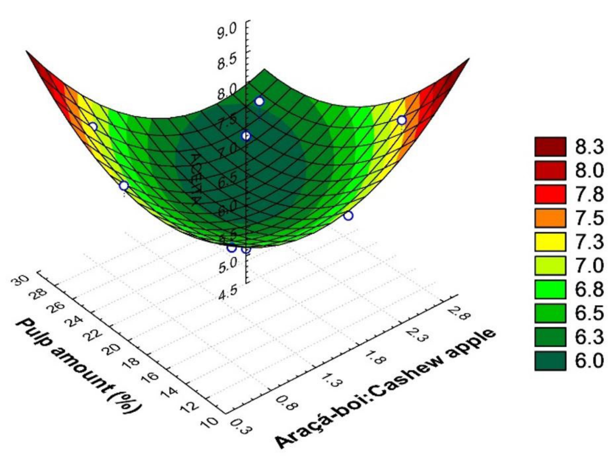

Figure 1. Response surface of CCD analysis to the overall acceptance of ready-to-drink beverage formulated with cashew-apple and aracá-boi pulps (x = pulp content and y = pulp ratio of araçá-boi: cashew apple).

3.3 Physicochemical determinations

The parameters analysed have importance in the quality characteristics of the beverages formulations, influencing the technological and sensory properties.

The pH, titratable acidity, and color (L*, a*, b* Chroma and Hue) presented no significant differences ($p > 0.05$) among treatments (Table 1).

These results show that adding omega-3 oil or encapsulated omega-3 does not cause modifications in these parameters short after processing. Also, when evaluating during the 120 days of storage time (data not shown), only a slight oscillation was observed over the storage period. This observed oscillation can be found in other fruit juices during storage. Freitas et al. (2006), evaluating the physical-chemical stability of acerola juice submitted to heat treatment and storage at 28 °C for 350 days, observed a slight increase in pH over time, attributing this behavior to the loss of citric acid during storage. Rebello et al. (2011) found acid values varying from 0.35-0.43 g citric acid.100 g^{-1} for the mixed nectar of araça-boi and mango with pulp proportions 30:70 and 70:30, respectively, values very similar to those found in this study.

All samples presented values of luminosity in the range 40.60 to 44.93 (Table 2).

The value L* varies from 0 (black) to 100 (white), which expresses the sample's luminosity or clarity. The value is inversely proportional to its coloration; the darker the product, the lower the value found for L*. Therefore, the samples that have high surface brightness with values close to 100. The luminosity (L*) differed statistically by the Tukey test between the formulations ($p < 0.05$) during the storage period, being possible to fit a linear model. Observing the L* values, it is possible to affirm that the beverages formulated with cashew apple and araça-boi presented intermediate clarity.

Observing the a* and b* values (Table 2), it was possible to affirm that the mixed cashew apple and araça-boi beverages tended to yellow. The same behavior was observed by Fernandes (2013) for cashew apple nectar.

The regression analysis of the a* value showed variation with the storage time, possibly adjusting to the linear model. However, this variation was not observed with the storage time for the value b*, represented by the mean value of time.

The chroma variable (C*) did not vary with the storage time and was presented only by the mean of 15.10. For the parameter C*, the results obtained were 14.02 (F1), 15.61 (F2) and 15.63 (F3). Abreu et al. (2011) found a value of 13.04 for their mixed drink of mango, passion fruit, and cashew apple fruit.

The value of the obtained Hue angle was around 114°. This value is quite similar to that found by Fernandes (2013), obtaining values ranging from 113.13° for cashew nectar sweetened with sucrose and 119.02° for cashew nectar sweetened with aspartame. The values are close to the range corresponding to the yellow (90°), which agrees with the positive values of b*.

Table 2. Physicochemical and color parameters of mixed cashew apple and araça-boi beverages: F1 (control), F2 (with omega-3 oil), and F3 (omega-3 encapsulated with cashew tree gum).

Parameters	Beverage treatments		
	F1	F2	F3
Titratable acidity[a]	0.40 ± 0.01	0.39 ± 0.02	0.39 ± 0.04
pH	3.05 ± 0.00	3.05 ± 0.01	3.05 ± 0.01
Soluble solids (°Brix)	11.67 ± 0.06	11.68 ± 0.02	11.74 ± 0.10
L*	42.36 ± 0.68	43.53 ± 0.62	44.77 ± 0.35
a*	-5.85 ± 0.10	-6.15 ± 0.02	-6.52 ± 0.15
b*	12.74 ± 0.37	14.35 ± 0.13	14.21 ± 0.59
Chroma	14.02 ± 0.37	15.61 ± 0.12	15.63 ± 0.53
Hue	114.67 ± 0.28	113.20 ± 0.24	114.66 ± 1.12

[a]Titratable acidity in g of citric acid 100 g^{-1}.

Table 3. Changes in sensorial parameters of mixed cashew-apple and araça-boi beverages: F1 (control), F2 (with omega-3 oil), and F3 (with omega-3 encapsulated with cashew tree gum) during storage (mean ± standard deviation).

Sensorial parameter	Storage (days)	Beverage treatments		
		F1	F2	F3
Overall acceptance	0	6.3 ± 1.9	6.0 ± 1.9	6.1 ± 1.8
	30	6.4 ± 1.7	5.5 ± 1.7	6.4 ± 1.5
	60	6.5 ± 1.5	5.1 ± 1.7	6.5 ± 1.6
	90	6.0 ± 1.8	4.7 ± 1.9	5.8 ± 1.9
	120	6.4 ± 1.5	-	5.9 ± 1.9
Appearance	0	6.9 ± 1.7	6.6 ± 1.8	6.7 ± 1.8
	30	6.9 ± 1.6	6.8 ± 1.7	6.9 ± 1.4
	60	7.1 ± 1.4	6.6 ± 1.7	7.2 ± 1.2
	90	6.9 ± 1.6	6.4 ± 1.9	6.8 ± 1.6
	120	7.1 ± 1.3	-	7.0 ± 1.7
Flavor	0	6.2 ± 1.9	5.9 ± 1.9	6.1 ± 2.0
	30	6.3 ± 1.6	5.3 ± 1.7	6.3 ± 1.6
	60	6.4 ± 1.5	4.9 ± 1.7	6.4 ± 1.6
	90	6.0 ± 1.9	4.4 ± 1.9	5.8 ± 1.9
	120	6.4 ± 1.3	-	5.7 ± 2.0

3.4 Sensory evaluation

The results of sensory evaluation of the beverages after processing and storage up to 120 days are presented in Table 3. They show only a slight difference among the treatments short after processing.

Sensorial parameters: hedonic scores from "1 = disliked extremely" to "9 = liked extremely".

Although the difference is significant ($p < 0.05$) among the treatments short after processing, all the scores were in the acceptable region, as "liked". During storage, the treatment F3, with the addition of omega-3 encapsulated with cashew tree gum, presented overall acceptance, appearance, and flavor similar to the control F1. In contrast, the F2 treatment with omega-3 oil reduces sensory scores with storage time, being rejected after 90 days of storage.

During storage, the results of treatments F1 and F3 have no significant differences ($p > 0.05$). The average value over the 120 days was between the "mildly liked" and "moderately liked" hedonic terms. The F2 formulation differed statistically ($p < 0.05$) for this attribute of the other two formulations. The overall acceptance varied with storage only for formulation F2, which had a linear decrease with storage, falling between the terms "neither liked nor disliked" and "slightly disagree" at the end of storage.

Observing these results, it can be seen that the Formulation F2, at time zero, kept the sensory acceptance close to the other two formulations F1 and F3, but, with the storage time (120 days), there was oxidation of the omega-3, giving it an odd taste. The use of encapsulated omega-3, as in F3 treatment, also demonstrate that the cashew-tree gum maintains relative stability during storage in this beverage under acidic conditions (pH 3.05 and 0.40g citric acid 100 g^{-1}) as it retains the sensory stability.

The results of the "check–all-that-apply" test shows that among the 22 descriptive terms, 16 were used to describe the mixed cashew apple and araça-boi beverage at least once during the 120 days of storage. Figure 2A, with the results, being the terms "fruity aroma", "cashew apple flavor", "acid taste", "sweet taste" more used.

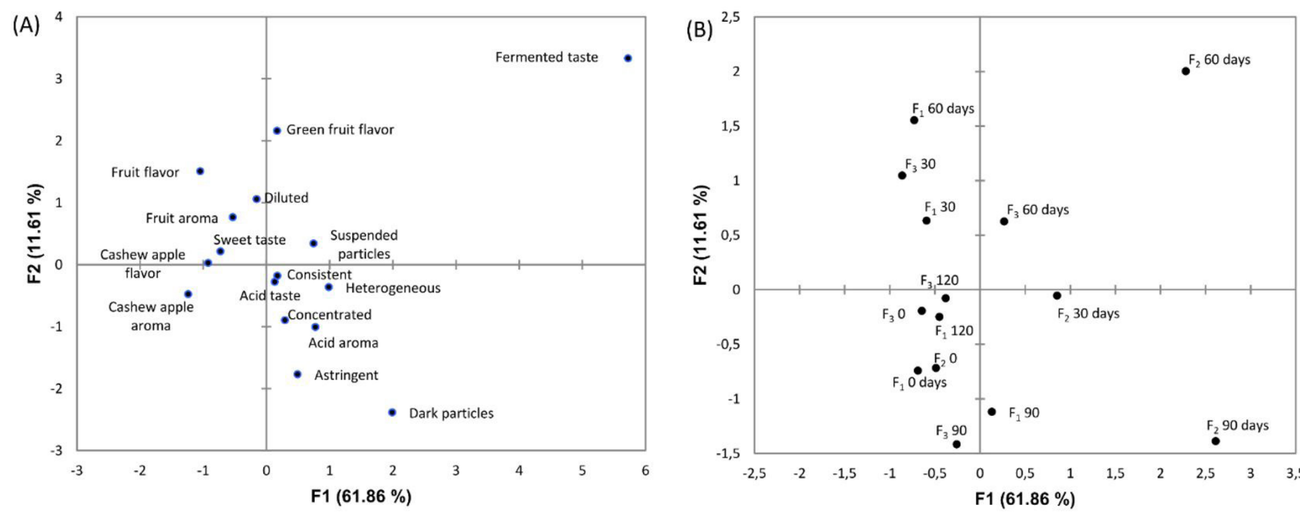

Figure 2. Sensorial descriptors obtained by "check-all-that-apply" analysis (A); and storage effect obtained by "check-all-that-apply" analysis (B). Treatments: F1 (control), F2 (with omega-3 oil), and F3 (with an omega-3 encapsulated with cashew tree gum). Storage: 0, 30, 60, 90 and 120 days.

The terms "pale", "sweet scent", "sugarcane aroma", "ripe fruit flavor", and "bitter juice" were never placed by the panelists. The term "yellow color" was removed from the evaluation because it was marked with the same intensity for all samples. The most punctuated characteristics by all the panelists were a yellow color, suspended particles, and acid taste. In a study by Cruz et al. (2013), 5-6 terms, out of a total of fifteen terms presented to consumers were used to describe the beverage.

Almost all of the descriptors surveyed by the panelists, except for the terms "cashew apple flavor" and "fruit flavor" exhibited equality throughout the assessed period for the three mixed cashew apple and araça-boi beverage formulations. It can be seen that the frequency of described "cashew apple aroma", "fruit flavor" and "cashew apple flavor" is inversely correlated with the formulation F2, probably due to the addition of 4,7,10,13,16,19-docosahexaenoic polyunsaturated fatty acid.

It can be observed in Figure 2B that the formulations F1 and F3 during the 120 days of storage are always close to each other and to the terms of better characteristics for this type of product since the formulation F2 in the first time was also found close to F1 and F3.

The storage time influenced the characteristics of "acid aroma" and "fermented flavor", which can be related to the added omega-3 polyunsaturated fatty acid.

It can be seen that the encapsulation of polyunsaturated fatty acid is an alternative to avoid loss of beverage acceptability caused by omega-3 addition. The formulation F3 presented the same characteristics of the formulation F1 (without the addition of omega-3 fatty acid), such as "cashew apple flavor" and "fruity aroma", rendering imperceptible the "fish aroma" during the 120 days of storage.

It should be noted that short after processing and along the 120 days of storage time, F1 (mixed cashew and araça-boi beverage) and F3 (mixed cashew and araça-boi mixed with encapsulated omega-3) were evaluated in the region of acceptable characteristics by the panellists, presenting overall acceptance means 6.3 and 6.1, for time 0 and 6.4 and 5.9 for the 120 days storage time for formulations F1 and F3, respectively. The formulation F2, which was added omega-3 oil, short after processing, had the same characteristics as the others, and the score decreased with the storage, and at 120 days storage, it was withdrawn from sensory evaluation because in the previous evaluation (90 days of storage) it had already reached rejection scores.

3.5 Rheological parameters

Evaluations of the rheological parameters were also performed during the storage of the juice formulations, showing small variations and, therefore, the rheological storage data are not shown in Supplementary Material (Table S1). For the Ostwald-de-Waelle model parameters, the observation was made that the data obtained showed a good fit to the model, with a determination coefficient close to the unity and the mean square error close to zero, for all samples analyzed (Supplementary Material Table S1). The rheological data obtained with the formulations F1, F2 and F3 fitted well to the Ostwald-de-Waelle model, with $R^2 > 0.72$, and mean square error close to zero for all evaluations performed during the 120 days storage. Murillo et al. (2017) evaluated the rheological behavior of carambola juice. They observed the variation of shear strength concerning the strain rate was adjusted to the models Ostwald-de-Waelle, Herschel-Bulkley, Bingham, and Newton equations.

For the consistency index, the F1 and F3 samples presented very similar results. The sample F2, with unencapsulated omega-3, has a greater consistency index. Therefore a conclusion can be made that the omega- 3 encapsulation favored maintaining the same rheological behavior of the control beverage, F1, concerning the rheological characteristics. For the behavioral index (n), in general, it can be concluded that such behavior was observed for all samples. At all storage times analyzed, all formulations showed less than the unit behavioral index, with non-Newtonian behavior and pseudo-plastic character.

The formulations F1 and F3 showed similar behavior, up to 90 days of storage. The F2 formulation showed lower performance index values for all analyzed times and may be considered less viscous, probably due to the direct addition of omega -3 in the mixed drink. Silva et al. (2012a) evaluated the rheological behavior of mixed nectars based on cashew apple, mango, and acerola pulps, noting the non-Newtonian behavior with a pseudoplastic character, a behavior similar to that obtained in this study.

For the parameters of the Herschel-Bulkley model, the data fitted well to the model, with the determination coefficient close to unity and mean square error close to zero for all samples at all storage times. The F2 formulation had higher initial stress than the other samples, except for 120 days. Regarding the Herschel-Bulkley consistency index, F3 showed a lower value than other samples, with values near the F1 results. Similar behavior was observed for the consistency index of the Ostwald-de-Waelle model, where the omega-3 encapsulation did not appear to influence the rheological characteristics of the samples.

Telis-Romero et al. (1999) used the Herschel-Bulkley model for the rheological parameters for the orange juice, verifying pseudo-plastic behavior. For the parameters of the Casson model, the observed data fitted well to the model, with the determination coefficient close to the unity and mean square error close to zero for all samples in all storage times. For this model, the analyzed samples showed initial stress and plastic viscosity similar to the Casson model results.

The rheological data doesn´t fit well to the Newton model when compared to other rheological models tested. The F3 sample showed lower Newtonian viscosity compared to F1 and F2 (Supplementary Material Table S1). In general, there were no changes in the rheological properties of the samples with storage time.

4 Conclusion

The mixed beverage was optimized, presenting better sensory acceptance when prepared with 18.6% cashew apple and 9.3% araça-boi. The omega-3 encapsulation with cashew tree gum does not modify the beverage's sensory acceptance and maintains it during storage, not being recommended the direct use of omega-3 oil. The omega-3 encapsulation is an efficient way of masking the odd taste caused by the omega-3 addition. When considering the physicochemical and sensory parameters, the juice is stable for up to four months of storage at room temperature.

All treatments showed non-Newtonian behavior, with pseudo-plastic character. The control and encapsulated omega-3 beverages presented similar rheological behavior. The beverage with unencapsulated omega-3 presented a greater consistency index and behavioral index. Thus, the observation can be made that the omega-3 encapsulation favored the constancy of the rheological characteristics of the beverage. The rheological parameters did not change with the samples' storage for the 120 days of storage.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Supplementary Material

Supplementary material accompanies this paper.

Table S1 - Parameters of the rheological models obtained soon after processing for mixed cashew apple and araça-boi beverages: F1 (control beverage, without omega-3), F2 (beverage added with omega-3), and F3 (beverage added with an omega-3 encapsulated with cashew tree gum)

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