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Effect of Incorporating Free or Encapsulated Ascorbic Acid in Chicken Frankfurters on Physicochemical and Sensory Stability

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Abstract: Sodium erythorbate, antioxidant and curing accelerator, used in meat products, have no vitamin functionality. Ascorbic acid (AA), in contrast, is a powerful antioxidant, but very unstable. The application of encapsulated AA in frankfurters could allow the incorporation of an antioxidant with vitamin functionality and improved stability. The aim of this study was to evaluate the application of AA microcapsules in frankfurters and the effects of their application on the product. Different analyses were conducted. The values obtained for mass loss, moisture content, water activity, pH and instrumental color were not significantly different among the treatments. The frankfurters containing the microcapsules exhibited the lowest hardness value (approximately 5,000 g), resulting in better scores in the sensory analysis. It was possible to apply the AA microcapsules without compromising the oxidative stability and physicochemical characteristics of the product, providing a promising method for protecting AA and producing fortified frankfurters.

Key words: AA, stability, thiobarbituric acid-reactive substances (TBARS), sensory acceptability, encapsulation, chicken frankfurters.

1. Introduction

Due to their property of inhibiting or retarding lipid oxidation of food, antioxidants have been widely employed in food formulations [1]. Such oxidation reactions are responsible for the development of unpleasant tastes and odors that make food unfit for consumption [2-4].

Light, heat and metal ions are some of the factors that affect oxidation in meat products, which cause the formation of free radicals that reduce the shelf life of these products [5, 6].

A meat emulsion is defined as a system that is composed of fat globules surrounded by a matrix formed from water and protein [7]. A frankfurter is a meat sausage produced using an emulsion that is formed using a special instrument called cutter, which mixes the ingredients, additives and condiments. The obtained mixture is incorporated in casings in which it receives heat treatment, and then these wrappers are removed in the final step [8]. Currently, emulsified meat products are produced with the addition of sodium erythorbate as an antioxidant and an accelerator of the curing reactions (a series of reactions resulting from nitrites interacting with the meat pigment myoglobin). Sodium erythorbate is the sodium salt of erythorbic acid, which is an isomer of ascorbic acid (AA) (vitamin C). However, sodium erythorbate has no vitamin functionality, thus conferring no benefit to the consumer's health.

AA, a natural antioxidant with vitamin functionality, occurs naturally in fruits and vegetables. However, it is very unstable when exposed to various factors, including, heat, light, a high oxygen concentration and high values of water activity, which limits its

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applications [4]. AA is already commonly used in frankfurters and can be used interchangeably with sodium erythorbate. Mancini et al. [9] compared the effects on coloration when sodium erythorbate or AA was added to meat that was packaged in a modified atmosphere, and no difference between the effects of the compounds was observed. For this reason, the focus of this work—the application of encapsulated AA in frankfurters—may be an innovative idea because this technique allows the incorporation of an effective antioxidant, with vitamin functionality and improved stability due to the protection conferred by microencapsulation process.

The aim of this study was to evaluate the use of AA in the free and encapsulated forms to replace sodium erythorbate in chicken frankfurters.

2. Materials and Methods

2.1 Materials

This study was conducted using chicken materials—fillets of leg meat (thigh and on-thigh) and skin. The entire experiment was conducted in two replications.

The standard formulation was prepared following the classification of the "frankfurter of chicken meat", according to the legislation [10]. The choice of the chicken materials was based on their high content of unsaturated fatty acids, which would facilitate demonstrating the functionality of the antioxidants that would be compared.

2.2 Methods

2.2.1 Microencapsulation Process

The method that was used to prepare the microcapsules was that adopted by Comunian et al. [11]. A single emulsion (water in oil (w/o)) was prepared using a 30% AA solution (weight/weight (w/w)) and corn oil in a ratio of 1:2 and polyglycerol polyricinoleate (PGPR) 90 as the emulsifier. This single emulsion was emulsified using a gelatin solution to obtain the double emulsion (water/oil/water (w/o/w)). The emulsifications (single and double emulsions) were performed at 12,000 rpm for 4 min and 10,000 rpm for 3 min using an UltraTurrax device (IKA, Staufen, Baden-Württemberg, Germany), respectively. Arabic gum solution was added to this emulsion by magnetic stirring.

To promote complex coacervation, the pH was adjusted to 4.4 using acetic acid at 40 °C under constant magnetic stirring, and then the temperature was gradually decreased to 10 °C in an ice bath. The material was stored for 24 h at 7 °C to promote decantation. Then, the coacervates were frozen in a freezer (-18 °C) and dried by sublimation using a freeze dryer (Terroni, São Carlos, Brazil).

2.2.2 Formulations

Frankfurters containing AA microcapsules were compared to products using free ascorbic acid, free AA together with the ingredients used in the encapsulation process, sodium erythorbate or without any type of antioxidant, resulting in five treatments (T1 to T5). The treatments (Table 1) were prepared using the basic formulation that was composed by 80% of fillet of chicken thigh and drumstick meat (w/w), 10% of chicken skin (w/w) from fresh meats and 10% of water (ice) (w/w). The thigh meat has been processed into frankfurter in the following day of the deboning.

2.2.3 Frankfurter Processing

The materials were weighed, and the mixture was comminuted in a rotating basin homogenizer—Cutter (Tecmafrig, São Paulo, Brazil) during 5 min and then removed from this equipment at a temperature below 14 °C. Then, the emulsions were embedded in cellulosic casings (permeable) with a diameter of 22 mm (Viscofan, São Paulo, Brazil) and manually tied into segments of 15 cm. The frankfurters were cooked in an oven until their internal temperature reached 72 °C, and then they were cooled using a water spray, vacuum packed and stored at 3 °C.

Table 1 Composition of each frankfurter treatment used in the study.

Composition/treatment	T1	T2	T3	T4	T5
Erythorbate	500 ppm*	--	--	--	--
AA	--	400 ppm*	--	400 ppm*	--
Encapsulated AA	--	--	27 g/kg**	--	--
Curing salt	0.25%	0.25%	0.25%	0.25%	0.25%
Condiment	1%	1%	1%	1%	1%
Salt (NaCl)	0.75%	0.75%	0.75%	0.75%	0.75%
Gelatin	--	--	--	7.8 g/kg	--
Arabic gum	--	--	--	7.8 g/kg	--
Corn oil	--	--	--	10 g/kg	--

T1: frankfurter containing erythorbate; T2: frankfurter containing free AA; T3: frankfurter containing encapsulated AA; T4: frankfurter containing free AA and the ingredients used during encapsulation process; T5: frankfurter without an antioxidant—control; *erythorbate and AA have the same antioxidant activity in different concentrations (the concentrations used are the equivalent concentrations); **27 g of microcapsules/kg of meat are equivalent to 400 ppm of free AA.

2.2.4 Evaluation of the Stability of the Meat Emulsion during Processing

The stability of the meat emulsion was evaluated using the method of Parks and Carpenter [12]. Samples of 50 g were packed in heat-resistant packaging, vacuum-sealed, weighed and heated in a water bath at 70 °C for 60 min. At the end of the set time, the samples were weighed again to calculate the weight loss.

2.2.5 Evaluation of the Oxidative Stability during Refrigerated Storage

To evaluate the oxidative stability during storage, the products were evaluated at 5, 12, 19, 26, 33 and 40 d of storage at 3 °C, using the thiobarbituric acid-reactive substances (TBARS) method. The amount of TBARS was calculated based on a standard curve and expressed in mg malonaldehyde/kg of sample.

2.2.6 Water Activity

The water activity was determined using an AQUALAB instrument (Decagon Devices, Pullman, WA, USA).

2.2.7 Moisture

The moisture content of the samples was determined using an Ohaus model MB 35 moisture analyzer (Ohio, USA).

2.2.8 Evaluation of pH Changes

The pH of the frankfurters was determined after 5, 12, 19, 26, 33 and 40 d of storage, using a pH meter (Hanna Meat pH meter HI 99163) equipped with a perforation electrode.

2.2.9 Evaluation of the Instrumental Texture Profile during Refrigerated Storage

The instrumental texture profile was analyzed using a texturometer (TAXT2i, Stable Micro Systems) that was calibrated using a standard 2 kg weight. The frankfurters had been previously cut into slices of 23 mm in length, which were compressed by up to 70% of this thickness using an aluminum probe (SMS P/20) in the pre-test, test and post-test at 25 °C, at a speed of 2.0 mm/s for a platform distance of 16 mm, using 10 frankfurters. The products were analyzed at 5, 12, 19, 26, 33 and 40 d of storage.

2.2.10 Determination of the Instrumental Color

This analysis was performed with a colorimeter (Mini Scan XE Plus) using the Hunter L*, a* and b* color system in samples that were stored for 5, 12, 19, 26, 33 and 40 d.

2.2.11 Evaluation of Sensory Acceptability during Refrigerated Storage

This analysis was conducted in individual booths, following the methodology of Meilgaard et al. [13]. The assays were performed using samples that were stored for 5, 20 and 40 d. The samples were evaluated using a nine-point hedonic scale (1-dislike extremely and nine-like extremely) for the attributes of taste,

texture, color, flavor and overall acceptability. Sixty untrained panelists of both sexes and different age groups participated in the test. Enjoying frankfurters was the only selection criterion. The recruited consumers were given a free and informed consent form to read and sign prior to performing the sample evaluations. A randomized complete block design was used, and the samples were served to the participants individually on disposable plastic plates that were encoded by three-digit numbers. Prior to the evaluations, the frankfurters were heated for 5 min in boiling water, cut into 2 cm cylinders and kept warm at 40 °C in an oven before being served to the consumers along with water and water-and-salt crackers.

2.2.12 Statistical Analyses

The obtained data were statistically analyzed using the statistical program statistic analysis system (SAS) version 9.2, employing an analysis of variance (ANOVA), completely randomized design and Tukey range test, with significance set to 5%.

3. Results and Discussion

3.1 Evaluation of the Stability of the Meat Emulsion during Processing, Moisture Content and Water Activity

The values obtained for the mass loss, moisture content and water activity were within the ranges of 15% to 17%, 52.8% to 55.5% and 0.964 to 0.975, respectively, with no differences ($P < 0.05$) observed among the treatments (Table 2). These results show that including AA microcapsules did not cause breakdown of the meat emulsion or alterations in the moisture content or the water activity of the frankfurter. The moisture values that were observed are within of the standard of identity and quality [10], which established a maximum moisture content of 65%.

The results obtained for the moisture content are in agreement with those obtained by Hayes et al. [14], who evaluated the effects of nutraceutical plants on the quality and stability of raw and cooked pork frankfurters. The moisture content values obtained ranged from 60.9% to 62.2% and from 53.0% to 53.2% for the raw and the cooked frankfurters, respectively.

The values obtained for the water activity were similar to those obtained by Filho et al. [15], in which frankfurters prepared using Tilapia fish had water activity values of approximately 0.98. Badr and Mahmoud [16], in studying the antioxidant activity of carrot juice in frankfurters, obtained a water activity value of 0.98.

3.2 Evaluation of the Oxidative Stability during Refrigerated Storage

The TBARS values for each treatment during 40 d of storage at 3 °C are presented in Table 3. The samples showed high TBARS values on the first day, ranging from 1.9 mg to 3 mg malonaldehyde/kg of sample. This result could be explained by lipid oxidation having occurred while the frankfurters were processed and cooked. There was no significant difference over the storage time for treatments T1 to T4, however, an increase ($P < 0.05$) in the concentration of malonaldehyde/kg of sample over time was observed in the control treatment (T5), proving the importance

Table 2 Mass loss, moisture content and water activity for each treatment.

Treatments	Mass loss (%)	Moisture content (%)	Water activity
T1	17.05 ± 1.39[a]	54.18 ± 5.18[a]	0.975 ± 0.003[a]
T2	17.19 ± 2.02[a]	54.11 ± 3.28[a]	0.975 ± 0.003[a]
T3	15.61 ± 1.89[a]	52.85 ± 7.64[a]	0.970 ± 0.007[a]
T4	16.36 ± 3.88[a]	53.84 ± 9.34[a]	0.974 ± 0.005[a]
T5	15.02 ± 1.40[a]	55.46 ± 3.13[a]	0.964 ± 0.002[a]

Different lowercase letters in the same column indicate significant differences according to the Tukey test, at 5% probability; T1: frankfurter containing erythorbate; T2: frankfurter containing free AA; T3: frankfurter containing encapsulated AA; T4: frankfurter containing free AA and the ingredients used during encapsulation process; T5: frankfurter without an antioxidant—control.

Table 3 TBARS values (mg malonaldehyde/kg of sample) of each treatment during 40 d of storage.

Treatments/days of storage	5	12	19	26	33	40
T1	$2.39 \pm 0.12^{a, A}$	$3.31 \pm 0.76^{a, A}$	$4.1 \pm 0.21^{a, A}$	$3.66 \pm 0.81^{a, A}$	$3.60 \pm 0.97^{a, A}$	$3.86 \pm 0.51^{a, A}$
T2	$2.88 \pm 0.37^{a, A}$	$3.26 \pm 1.64^{a, A}$	$3.99 \pm 0.46^{a, A}$	$3.47 \pm 0.04^{a, A}$	$3.52 \pm 1.36^{a, A}$	$3.87 \pm 0.98^{a, A}$
T3	$3.02 \pm 1.61^{a, A}$	$3.91 \pm 0.59^{a, A}$	$3.66 \pm 0.49^{a, A}$	$3.87 \pm 1.08^{a, A}$	$3.62 \pm 1.10^{a, A}$	$3.38 \pm 1.45^{a, A}$
T4	$2.75 \pm 1.34^{a, A}$	$3.61 \pm 0.98^{a, A}$	$4.22 \pm 0.48^{a, A}$	$4.00 \pm 0.91^{a, A}$	$3.93 \pm 0.37^{a, A}$	$3.11 \pm 2.01^{a, A}$
T5	$1.91 \pm 0.71^{b, A}$	$3.6 \pm 1.20^{ab, A}$	$5.87 \pm 0.96^{a, A}$	$4.04 \pm 0.81^{ab, A}$	$4.74 \pm 0.25^{ab, A}$	$5.51 \pm 0.26^{a, A}$

Different lowercase letters in the same row and different capital letters in the same column indicate significant differences according to the Tukey test, at 5% probability; T1: frankfurter containing erythorbate; T2: frankfurter containing free AA; T3: frankfurter containing encapsulated AA; T4: frankfurter containing free AA and the ingredients used during encapsulation process; T5: frankfurter without an antioxidant—control.

of including an antioxidant. Thus, it can be inferred that the encapsulated AA was released from the microcapsules, possibly due to changes in the ionic strength, pH or due to the temperature increase—heat treatment—in the product that promoted its acting as an antioxidant.

Trindade et al. [17] studied the oxidative stability during the frozen storage of mechanically separated hen meat that had been pre-blended with antioxidants, and the TBARS values that they obtained were lower than those found in this study at the beginning of the storage period, but similar to those at the end of the storage period, ranging from 0.9 mg malonaldehyde/kg to 3.84 mg malonaldehyde/kg of sample after 99 d of frozen storage. Hayes et al. [14] evaluated the effects of plant-derived nutraceuticals on the quality and shelf life of raw and cooked pork frankfurters and observed an increase in the amount of TBARS in the control samples during 21 d of storage at 4 °C (from 0.43 mg malonaldehyde/kg to 1.13 mg malonaldehyde/kg of sample and 0.81 mg malonaldehyde/kg to 1.39 mg malonaldehyde/kg of sample for the raw and the cooked frankfurters, respectively). An increase in the TBARS value was obtained by Badr and Mahmoud [16] when they studied the antioxidant activity of carrot juice in irradiated sausages during refrigerated and frozen storage. The malonaldehyde concentration increased from 0.23 mg/kg to 2 mg/kg in the control sample within 12 d of refrigerated storage. The other treatments (sausage containing non-concentrated carrot juice and those containing 35% and 60% concentrates) showed a slight but not significant increase in the TBARS. Maqsood et al. [18] studied the effect of tannic acid and kiam wood extract on the lipid oxidation of fish frankfurters during refrigerated storage. The TBARS values of all of the analyzed treatments increased during 20 d of storage, reaching values of 7 mg malonaldehyde/kg to 12 mg malonaldehyde/kg of sample.

3.3 Evaluation of the pH Changes

The pH values that were observed in the different treatments during 40 d were within the range of 5.8 to 6.2, with no difference among the treatments or throughout the storage period ($P > 0.05$). It was expected that the sausages containing free AA (T2 and T4) would have a lower pH compared to those of the other treatments, with consequent damage to the structures of the myofibrillar proteins, which did not occur. It appeared that the buffering capacity of the system was sufficient for the AA concentration adopted (400 ppm), preventing variation in the pH. According to Beraquet [19], chicken meat usually presents pH values in the range of 5.8 to 5.9 for the breast meat and 6.2 to 6.3 for the thigh meat. Therefore, the pH of the chicken meat was maintained even after processing and over the 40 d of analysis.

The data obtained in this study corroborated those obtained by Trindade et al. [17], who observed pH values ranged from 6.4 to 6.6 after 99 d of storage. The pH values observed by Kulkarni et al. [6] were within the ranges of 6.1 to 6.5 and 6.2 to 6.4 at time zero and after four months of storage, respectively.

3.4 Evaluation of the Instrumental Texture Profile during Refrigerated Storage

The hardness values obtained for each treatment throughout 40 d of storage are shown in Table 4. There were differences ($P < 0.05$) among the treatments during the same periods; however, the profiles of the same treatment did not vary ($P > 0.05$) during the storage period.

Treatments T3 and T4 showed less resistance to external deformation compared with the other treatments, showing hardness values that were almost 30% lower than those of T1, T2 or T5. According to Hedrick et al. [7], meat proteins—myofibrillar proteins (actin and myosin)—are the main components that are responsible for the hardness of frankfurters. Thus, the fact that T3 and T4 showed less hardness could be explained by the greater quantity of ingredients present in the formulations, and consequently a small reduction in the amounts of meat proteins. The lowest hardness value was positively correlated with the overall acceptability in the sensory evaluation, which means that the lowered resistance presented by the treatment containing microcapsules (T3) resulted in a higher acceptance of the consumer (Table 5).

Filho et al. [15] evaluated the inclusion of the mechanically separated meat (MSM) of fish in frankfurter prepared from fillets of Nile tilapia. The hardness values decreased from 13,196 g (0% of MSM) to 881 g (100% of MSM). Maqsood, Benjakul and Balange [18] evaluated the effect of adding tannic acid and kiam wood extract to fish frankfurters on their properties during refrigerated storage and obtained hardness values in the range of 37.33 N to 38.77 N on day zero and 28.32 N to 34.21 N at 20 d of storage. Notably, the hardness values of the fish frankfurters were lower than those of the chicken frankfurters.

Hayes et al. [14] evaluated the effect of adding lutein, sesamol, ellagic acid and olive extract to pork frankfurters. In this case, the hardness values that were observed were between 57.99 N and 75.86 N and between 68.44 N and 76.93 N at 2 d and 12 d of refrigerated storage. The increase that occurred between the two time points was related to the destabilization of the meat emulsion due to the separation of water and meat in the protein matrix.

3.5 Determination of the Instrumental Color

To determine the instrumental color, the values of L^*, a^* and b^* were measured and found to be within the range of 64 to 70, 4.3 to 5.8 and 9.7 to 11.6, respectively. There was no significant difference among the treatments and the selected time intervals. Thus, the application of microcapsules caused no change in the color of the frankfurters. The values of a^* and b^* are low due to the absence of dye. Furthermore, chicken meat was used, which has lower myoglobin content compared with that of red meats.

Maqsood, Benjakul and Balange [18] studied the effect of supplementing fish frankfurters with tannic acid and kiam wood extract on their properties during refrigerated storage. The authors analyzed the effect of

Table 4 Hardness (g) of each treatment during 40 d of storage.

Days of storage/treatments	T1	T2	T3	T4	T5
5	7,108.6 ± 1,232.8$^{a, A}$	7,005.7 ± 770.5$^{a, AB}$	5,200.2 ± 744.9$^{a, C}$	5,819.8 ± 792.6$^{a, BC}$	6,132.1 ± 942.1$^{a, ABC}$
12	7,241.4 ± 683.2$^{a, A}$	6,471.8 ± 1,137.5$^{a, A}$	4,715.6 ± 668.8$^{a, B}$	5,059.1 ± 645.2$^{a, B}$	6,563.2 ± 725.6$^{a, A}$
19	6,229.4 ± 1,107.7$^{a, A}$	6,743.3 ± 792.9$^{a, A}$	4,765.6 ± 713.8$^{a, B}$	5,854.2 ± 882.5$^{a, AB}$	6,788.8 ± 1,123.6$^{a, A}$
26	6,835.4 ± 5,877.6$^{a, A}$	6,902.5 ± 771.8$^{a, A}$	4,538.3 ± 593.6$^{a, C}$	5,469.2 ± 741.4$^{a, BC}$	6,108.9 ± 921.2$^{a, AB}$
33	6,863.4 ± 1,102.6$^{a, AB}$	7,343.7 ± 349.1$^{a, A}$	5,384.1 ± 796.3$^{a, C}$	5,503.8 ± 824.9$^{a, C}$	6,063.7 ± 833.1$^{a, BC}$
40	7,269.04 ± 689.9$^{a, A}$	6,775.7 ± 1,041.7$^{a, A}$	5,139.8 ± 954.8$^{a, C}$	5,534.9 ± 883.2$^{a, BC}$	6,338.5 ± 774.9$^{a, AB}$

Different lowercase letters in the same row and different capital letters in the same column indicate significant differences according to the Tukey test, at 5% probability; T1: frankfurter containing erythorbate; T2: frankfurter containing free AA; T3: frankfurter containing encapsulated AA; T4: frankfurter containing free AA and the ingredients used during encapsulation process; T5: frankfurter without an antioxidant—control.

Table 5 Scores obtained for each attribute in the sensory analysis.

	Treatments/days of storage	5	20	40
Flavor	T1	$6.4 \pm 1.5^{a, A}$	$6.8 \pm 1.4^{a, A}$	$6.5 \pm 1.4^{a, A}$
	T2	$5.6 \pm 1.7^{a, B}$	$6.4 \pm 1.7^{a, A}$	$6.2 \pm 1.7^{a, A}$
	T3	$6. 2 \pm 1.4^{a, AB}$	$6.8 \pm 1.6^{a, A}$	$6.6 \pm 1.7^{a, A}$
	T4	$6.4 \pm 1.4^{a, AB}$	$6.8 \pm 1.5^{a, A}$	$6.9 \pm 1.7^{a, A}$
	T5	$5.9 \pm 1.7^{a, AB}$	$6.2 \pm 1.8^{a, A}$	$6.2 \pm 1.6^{a, A}$
Color	T1	$6.1 \pm 1.7^{a, A}$	$6.1 \pm 1.7^{a, A}$	$6.5 \pm 1.6^{a, A}$
	T2	$5.5 \pm 1.8^{a, AB}$	$5.8 \pm 1.7^{a, A}$	$6.1 \pm 1.9^{a, A}$
	T3	$5.6 \pm 1.8^{a, AB}$	$6.1 \pm 1.6^{a, A}$	$6.0 \pm 1.9^{a, A}$
	T4	$5.5 \pm 1.8^{a, AB}$	$5.9 \pm 1.7^{a, A}$	$5.7 \pm 1.8^{a, A}$
	T5	$5.1 \pm 1.9^{a, B}$	$5.7 \pm 1.6^{a, A}$	$5.5 \pm 1.9^{a, A}$
Texture	T1	$5.4 \pm 1.8^{a, B}$	$5.8 \pm 1.9^{a, B}$	$5.6 \pm 1.8^{a, B}$
	T2	$5.5 \pm 1.7^{a, B}$	$6.0 \pm 1.7^{a, B}$	$5.9 \pm 2.1^{a, B}$
	T3	$6.7 \pm 1.6^{a, A}$	$6.9 \pm 1.4^{a, A}$	$6.8 \pm 1.8^{a, A}$
	T4	$6.5 \pm 1.5^{a, A}$	$6.9 \pm 1.6^{a, A}$	$6.8 \pm 1.7^{a, A}$
	T5	$5.5 \pm 1.7^{a, B}$	$5.5 \pm 1.8^{a, B}$	$5.4 \pm 1.8^{a, B}$
Taste	T1	$6.4 \pm 1.3^{a, AB}$	$6.4 \pm 1.5^{a, AB}$	$6.0 \pm 1.7^{a, B}$
	T2	$6.2 \pm 1.6^{a, AB}$	$6.4 \pm 1.9^{a, AB}$	$6.0 \pm 1.8^{a, B}$
	T3	$6.8 \pm 1.5^{a, A}$	$6.9 \pm 1.6^{a, A}$	$7.0 \pm 1.6^{a, A}$
	T4	$6.7 \pm 1.4^{a, A}$	$7.0 \pm 1.6^{a, A}$	$6.8 \pm 1.7^{a, AB}$
	T5	$5.7 \pm 1.7^{a, B}$	$5.9 \pm 1.9^{a, B}$	$5.9 \pm 1.8^{a, B}$
Overall acceptability	T1	$6.2 \pm 1.4^{a, AB}$	$6.4 \pm 1.4^{a, AB}$	$6.0 \pm 1.5^{a, BC}$
	T2	$5.9 \pm 1.5^{a, AB}$	$6.3 \pm 1.7^{a, AB}$	$6.0 \pm 1.6^{a, BC}$
	T3	$6.6 \pm 1.4^{a, A}$	$6.8 \pm 1.5^{a, A}$	$6.9 \pm 1.4^{a, A}$
	T4	$6.6 \pm 1.2^{a, A}$	$6.8 \pm 1.5^{a, A}$	$6.7 \pm 1.6^{a, AB}$
	T5	$5.6 \pm 1.6^{a, B}$	$5.8 \pm 1.6^{a, B}$	$5.8 \pm 1.7^{a, C}$

Different lowercase letters in the same row and different capital letters in the same column for each attribute indicate significant differences according to the Tukey test, at 5% probability; T1: frankfurter containing erythorbate; T2: frankfurter containing free AA; T3: frankfurter containing encapsulated AA; T4: frankfurter containing free AA and the ingredients used during encapsulation process; T5: frankfurter without an antioxidant—control.

these additions on the color of the samples and observed that there was no significant difference among the treatments. The *L**, *a** and *b** values that were observed were in the range of 73.34 to 76.32, 4.61 to 4.96, and 20.69 to 21.85, respectively. In that case, because the products were fish frankfurters, these treatments exhibited a higher brightness, a lower tendency toward redness and a greater tendency toward yellowness than those the frankfurters examined in this study.

The *L** values that were observed corroborated the data presented by Hayes et al. [14] when they studied the effect of adding lutein, sesamol, ellagic acid and olive extract to pork frankfurters that were stored in aerobic packages in a modified atmosphere. In their study, the observed *L** values ranged from 54.27 to 62.05 at 21 d of storage, indicating that no change had occurred during this period. Thus, the frankfurters had maintained their brightness in the same manner as had the products examined in this study.

3.6 Evaluation of the Sensory Acceptability during Refrigerated Storage

The results of the sensory acceptability evaluations revealed significant differences in all of the assessed attributes (flavor, color, texture, taste and overall acceptability) among the treatments, with treatment T3 (containing the AA microcapsules) being the one most preferred by consumers (Table 5). No significant changes in any of the treatments in the attributes that

were evaluated were observed during the storage period, which proved the oxidative stability of the product during these 40 d. Even in the case of the control treatment, in which the TBARS value increased over time, the consumers did not assign low scores at the end of the storage period. The scores assigned for each attribute during 40 d of storage are shown in Table 5.

According to Counsell and Hornig [20], rancid odors can be detected by trained and untrained panelists when the TBARS values reach the ranges of 0.1 mg malonaldehyde/kg to 1.0 mg malonaldehyde/kg and 0.6 mg malonaldehyde/kg to 2 mg malonaldehyde/kg of sample, respectively. However, even when the TBARS values were higher than these levels (from 1.91 mg malonaldehyde/kg to 3 mg malonaldehyde/kg and 3.11 mg malonaldehyde/kg to 5.5 mg malonaldehyde/kg at 5 d and 40 d, respectively), the panelists did not reject the samples that they evaluated during the 40 d of storage, assigning scores between “liked it slightly” and “liked it regularly” for the most attributes.

The attribute that received the lowest scores was the color due to the absence of dye in the formulation. Uyhara et al. [21] studied the effect of adding the natural dyes urucum and cochineal carmine to frankfurters prepared with Nile tilapia. It was observed that the treatments containing the pigments received the highest scores for the attribute of color compared with the treatments lacking the dyes.

There was a significant difference among the textures of the treatments with the best scores being given to the treatments with the lower hardness values (Table 5). Treatments T3 and T4 (the formulations containing AA microcapsules or free encapsulating ingredients), which received the best grades of sensory acceptance, were precisely the ones with the lowest hardness values. This result is most likely due to the consumers being accustomed to their having the texture of the sausages that are generally found in the market, which have a low hardness value.

Regarding the overall acceptability, there was a significant difference among the treatments in each storage period. It was observed that treatment T3 was the most accepted treatment, followed by treatment T4. The high scores for their texture and flavor attributes lead to greater global acceptance of these treatments. The frankfurters containing Nile tilapia produced by Uyharaet et al. [21] when they studied the effects of adding dyes to these frankfurters received values of global acceptance within the range of 5.63 to 5.83, which were much lower than those received for the chicken frankfurters containing the AA microcapsules.

4. Conclusions

It was possible to produce frankfurters using AA as an antioxidant. All treatments obtained values of moisture and water activity consistent with those normally found for frankfurters and showed no change in pH values and instrumental color. TBARS values showed that it was possible to release the encapsulated AA by disintegration of the microcapsules during processing and/or storage due to the oxidative stability presented in the sample. Moreover, the sausages that were produced using encapsulated AA showed good sensory acceptability.

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