Study of vitamin C degradation in acerola pulp during ohmic and conventional heat treatment

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A B S T R A C T

Vitamin C degradation in acerola pulp during thermal treatment by ohmic and conventional heating was evaluated. The ohmic heating technology was studied using a Central Composite Rotatable Design, and two variables were evaluated: the solids content of the pulp (2–8 g/100 g) and the heating voltage (120–200 V). The results indicate that ascorbic acid degradation was significantly influenced by both of the aforementioned variables. The total vitamin C degradation was influenced by the linear and the quadratic effects of the voltage. A comparative evaluation of the conventional and the ohmic heating processes showed that ohmic heating, when performed with low voltage gradients, promoted degradation of both the ascorbic acid and the total vitamin C in a manner similar to conventional heating. However, high voltage gradients induced greater ascorbic acid degradation because of electrochemical reactions. These reactions increased when high electric fields were applied, producing compounds that catalyzed the degradation pathways of ascorbic acid in the presence of oxygen.

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1. Introduction

Acerola (*Malpighia emarginata* D.C.), also known as Barbados Cherry, is a tropical fruit of great economic and nutritional value because of its high content of vitamin C, which is associated with the presence of carotenoids, anthocyanins, iron and calcium. Acerola's consumption *in natura* is limited because it is a small fruit with relatively large seeds and is very perishable. The fruit, however, has a good pulp yield, facilitating the development of several industrial products. Acerola has been processed in the form of juices, jams, ice creams, syrups, liqueurs and fruit syrups, among other products (Soares Filho & Oliveira, 2003). In this context, processed products, such as frozen pulp and concentrated pulp, have economic importance; pulp production is a profitable activity that allows the freshly harvested perishable fruit to be stored and reprocessed off-season.

The preservation of nutritional constituents during processing represents a major challenge for the traditional techniques of pulp production. Processing generally involves heat treatment that can reduce the nutritional and organoleptic quality of the product. Over the years, new processing technologies have emerged to reduce or to eliminate the exposure of the fruit to heat. Ohmic heating is one

alternative pulp pasteurization process. This technology can provide rapid and uniform heating, resulting in less thermal damage to labile substances such as vitamins and pigments (Castro, Teixeira, Salengke, Sastry, & Vicente, 2004; Sarang, Sastry, & Knipe, 2008).

Ohmic heating is defined as a process where electric currents pass through foods to heat them by internally generated energy, without involving any heating medium or heat transfer surface (Castro, Teixeira, Salengke, Sastry, & Vicente, 2003). This heating technology is particularly interesting for viscous products and foods containing particulates because it simultaneously generates heat in both phases and does not need to transfer heat either through a solid–liquid interface or within a solid (de Alwis & Fryer, 1990; Imai, Uemura, Ishida, Yoshizaki, & Noguchi, 1995; Sastry & Palaniappan, 1992). The potential applications of this technique in the food industry are very wide and include blanching, evaporation, dehydration, fermentation and pasteurization (FDA, 2000; Sarang et al., 2008).

L-ascorbic acid (*AA*) is one of the most important natural antioxidants supplied by fruits and vegetables; it is the main biologically active form of vitamin C. This vitamin, present in high levels in the acerola pulp, is used as a quality index because it is very sensitive to degradation during processing and storage (Lee & Kader, 2000). The degradation of vitamin C occurs under both aerobic and anaerobic conditions. The first case is characterized by the reversible oxidation of *AA* to L-dehydroascorbic acid (*DHA*), which also exhibits biological activity. Further irreversible

oxidation of *DHA* generates diketogulonic acid (*DCG*), which has no biological function. The degradation of vitamin C under anaerobic condition is not yet elucidated due to its complexity (Fennema, 1996). Vitamin C is most sensitive to destruction when the product is subjected to adverse handling and storage conditions. Losses are increased by extended storage, high temperatures, low relative humidity, physical damage, and chilling injury (Lee & Kader, 2000).

The objective of this study is to evaluate the degradation of vitamin C in acerola pulp after thermal processing by both ohmic and conventional heating. The ohmic heating technology was studied using a Central Composite Rotatable Design in which the variables evaluated were the total solids content of the pulp (2–8 g/100 g) and the heating voltage (120–200 V; electric field strength 21–36 V cm^{-1}).

2. Materials and methods

2.1. Acerola pulp

Acerola pulp, supplied by *Mais Fruta* Company, was received frozen in packs of 100 g and was stored at −18 °C for later analyses. The samples were diluted by adding deionized water to adjust the total solids content to five different amounts (ranging from 2.0 to 8.0 g/100 g) and then homogenized using a magnetic stirrer (*Instrulab*, Model ARE, Brazil).

2.2. Ohmic heating process

2.2.1. Experimental setup

The experimental setup comprises a power supply, a variable transformer (*Sociedade Técnica Paulista LTDA*, model Varivolt, Brazil), a stabilizer (*Forceline*, model EV 1000 T/2-2, Brazil), a data acquisition system, a computer and an ohmic cell. The experimental apparatus is schematically shown in Fig. 1. The voltage across and the current through the ohmically heated sample were measured using voltage and current transducers. The temperature was monitored by two temperature sensors (*Novus*, model pt-100, Brazil). These variables were recorded at constant time intervals by a data logger (*Novus*, model Field logger, Brazil) linked to a computer. The ohmic cell was made of a 400 mL Pyrex glass vessel and was equipped with a water jacket. The lid of the vessel contained four ports for temperature sensors and two ports for the electrodes. The electrodes were made of platinum with cross-sectional areas of 7.0 cm^2. The cell was placed on a magnetic stirrer (*Instrulab*, Model ARE, Brazil) to promote agitation of the product during heating. A temperature-controlled water bath (Lauda, RM 12, Brazil) was connected to the ohmic cell to cool the sample after heating.

The samples were heated to 85 °C for 3 min. These conditions were chosen considering studies carried out by Kumar, Mohan, and Murugan (2008) that showed that polyphenoloxidase enzyme from acerola loses stability at temperatures above 75 °C. The aforementioned authors found that a heat treatment at 85 °C for 3 min reduces the enzyme activity to values close to 10%.

The samples were heated at voltages determined by a factorial design. When the sample reached the desired temperature, the voltage was reduced of approximately 50% to maintain the temperature constant during 3 min. After this time, the water bath was turned on and cool water passed through the water jacket of the cell.

2.2.2. Experimental design and data analysis

A central composite rotatable design was used to design the tests for the ohmic heating process, considering two variables: the solids content of the pulp (2–8 g/100 g) and the heating voltage (120–200 V). The statistical design consisted of a 2^2 factorial with four axial points and four center points, giving a total of twelve combinations. The experimental design is shown in Table 1, where X_1 and X_2 are the real values of the heating voltage and the solids content of the pulp, respectively. The dependent variables were the ascorbic acid degradation (D_{AA}) and total vitamin C degradation (D_{VTC}).

The solids content was chosen as independent variable because it affects the electrical conductivity of the product. The rate of ohmic heating is directly proportional to the square of the electric field strength and the electrical conductivity. Changing the rate of the ohmic heating results in different times of heating and this may influence on vitamin C degradation.

The statistical analyses were carried out using Statistica® 5.0 (Statsoft Inc., Tulsa, OK, USA).

2.3. Conventional heating processing

The conventional heating processing was carried out in a 200 mL Pyrex glass vessel equipped with a water jacket. Two thermostatic water baths (*Lauda*, model T Alemanha; *Lauda*, RM 12, Brazil) were used to heat and cool the samples. Hot water (86 °C) circulated in the jacket of the vessel to heat the sample, and refrigerated water (4 °C) was used to cool it rapidly at the end of the heat treatment. The vessel was kept on a magnetic stirrer (*Instrulab*, Model ARE, Brazil) to promote agitation of the acerola pulp during heating. Samples with 2.00, 2.88, 5.00, 7.12 and 8.00 g/100 g of solids content were heated to 85 °C and kept at this temperature for 3 min.

During the experiments, the temperature was monitored using type T thermocouples and a data acquisition system (*Novus*, model Field logger, Brazil), which was linked to a computer.

2.4. Determination of total vitamin C and ascorbic acid contents

The vitamin C content of the samples before and after the heating process was determined using a high performance liquid chromatograph (Perkin Elmer Corp., Series 200, Norwalk, CT, USA). The column used was a reverse C$_{18}$ (Brownlee Validated, RP-18,
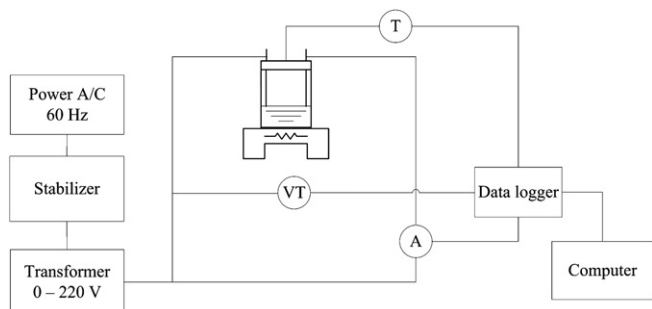

Fig. 1. Schematic diagram of the ohmic heating setup.

Table 1
Experimental design for ohmic heating experiments.

Levels	VT[a] (V) X_1	SC[b] (g/100 g) X_2
−1.41	120	2.00
−1	132	2.88
0	160	5.00
1	188	7.12
1.41	200	8.00

[a] heating voltage.
[b] solids content.

Spheri-5, PerkinElmer, Waltham, Massachusetts, USA). Isocratic chromatographic separation was carried out using a mobile phase of Milli-Q water with acetic acid (0.1 mL/100 mL) and methanol in a relative proportion of 95:5 (mL:mL). The eluent flow-rate was 0.7 mL/min, and the column temperature was 30 °C. Ascorbic acid was identified by comparing the retention time of the sample peak with that of the ascorbic acid standard at 254 nm. Quantification was carried out using external standardization.

The term vitamin C refers to *AA* and *DHA* because both have vitamin activity. The quantification of *AA* before and after the reduction of *DHA* to *AA* using DL-dithiothreitol allows an indirect estimation of *DHA* levels. To measure the total concentration of vitamin C, 1.5 g of sample and 4 mL of 0.0154 g mL^{-1} DL-dithiothreitol were added into a 15 mL centrifuge tube. The tube was shaken for 30 s and then placed in a dark room for 20 min. Later, 1.5 mL of 0.045 g mL^{-1} metaphosphoric acid solution was added to the contents of the 15 mL centrifuge tube. The tube was shaken for another 30 s and subsequently centrifuged (*Cientec*, model 500R, Brazil) for 10 min at 5 °C (3000× g). Afterward, the solution was filtered through a PTFE membrane of 0.45 μm, and 40 μL was injected into the HPLC system.

To quantify ascorbic acid content, 5 g of sample and 5 mL of 0.045 g mL^{-1} metaphosphoric acid solution were placed into a 15 mL centrifuge tube. The tube was shaken for 30 s and centrifuged (*Cientec*, model 500R, Brazil) for 10 min at 5 °C (3000× g). Finally, the solution was filtered using a PTFE membrane of 0.45 μm, and 40 μl was injected into the HPLC system. All the HPLC analyses were done, at least, in triplicate.

The reliability of the method was evaluated in terms of sensitivity, precision and recovery. The detection and quantification limits were 0.88 and 2.92 mg mL^{-1}, respectively. The precision of the method ranged from 0.2 to 1.3%, and the rate of recovery was above 95%.

3. Results and discussion

3.1. Ohmic heating process

3.1.1. Ascorbic acid degradation

The initial ascorbic acid content (C_{AAi}), the final ascorbic acid content (C_{AAf}) and the degradation percentage (D_{AA}) of each experiment are listed in Table 2. The results show that experiments 2 and 4, conducted with higher voltages (equivalent to an electric field strength of 34 V cm^{-1}), presented higher D_{AA}, approximately 10%. Moreover, experiment 7, conducted with the lowest voltage (electric field strength of 21 V cm^{-1}), showed the lowest D_{AA} of approximately 3%. As observed in Table 2, independent of the solids content of the pulp, lower values of D_{AA} were obtained using lower voltages.

Table 2
Initial and final ascorbic acid content and the degradation percentage obtained after the ohmic heating process.

Exp.	VT (V)	SC (g/100 g)	C_{AAi} (mg/100 g, b.s.)	C_{AAf} (mg/100 g, b.s.)	D_{AA} (%)
1	132	2.88	8.93 ± 0.02	8.61 ± 0.06	3.66
2	188	2.88	8.69 ± 0.03	7.79 ± 0.04	10.35
3	132	7.12	8.93 ± 0.02	8.60 ± 0.02	3.71
4	188	7.12	8.69 ± 0.03	7.77 ± 0.03	10.63
5	160	2.00	8.79 ± 0.03	8.17 ± 0.06	7.06
6	160	8.00	8.71 ± 0.03	8.15 ± 0.03	6.41
7	120	5.00	8.80 ± 0.03	8.53 ± 0.03	3.08
8	200	5.00	8.79 ± 0.03	7.97 ± 0.02	9.33
9	160	5.00	8.93 ± 0.02	8.31 ± 0.03	6.97
10	160	5.00	8.80 ± 0.03	8.18 ± 0.02	6.89
11	160	5.00	8.80 ± 0.03	8.19 ± 0.03	6.98
12	160	5.00	8.79 ± 0.03	8.19 ± 0.03	6.91

Vikram, Ramesh and Prapulla (2005) studied the kinetics of ascorbic acid degradation during ohmic heating of orange juice by applying an electric field strength of 42 V cm^{-1}; after 3 min of heating at 90 °C, D_{AA} was approximately 35%. Assiry, Sastry, and Samaranayake (2003) evaluated the ascorbic acid degradation in a buffer solution of pH 3.5 using a bath ohmic heater with uncoated stainless steel electrodes; after 10 min of heating at 80 °C, D_{AA} was approximately 13%. Lima, Heskitt, Burianek, Nokes, and Sastry (1999) used ohmic heating to heat orange juice for 30 min at 90 °C with an electric field of 18.2 V cm^{-1}, and D_{AA} was approximately 21%. Clearly, the literature values for ascorbic acid degradation in food products are quite varied. This behavior may be due to vitamin C degradation mechanisms that differ depending on the nature of the food system or reaction medium. Degradation can occur through aerobic and/or anaerobic pathways, depending on a number of factors such as pH, acidity, metal ions, light, humidity, water activity, temperature, presence of amino acids, carbohydrates, lipids and enzymes, among others (Gregory, 1996).

A statistical analysis was conducted to evaluate the influence of the voltage (*VT*) and the solids content (*SC*) on the D_{AA}. Table 3 presents the analysis of the perturbations caused by the factors on D_{AA}. This table also presented the same analysis for D_{VTC}, which will be discussed later. Linear and quadratic effects of *VT* significantly influenced D_{AA} at a 95% confidence level. *VT* exerted a positive effect on D_{AA}, indicating that D_{AA} increased when *VT* changed from the minimum to the maximum value. The linear effect of *SC* also significantly influenced D_{AA} but it is worth mentioning that its *p* coefficient was 0.019, a value very close to the stipulated confidence limit. It is also possible to observe that the influence of voltage was stronger than the influence of solids content on D_{AA}.

Lima et al. (1999) verified that the presence of an electric field had no significant effect on the ascorbic acid degradation in orange juice. Although there was electrolysis and metal corrosion when stainless steel electrodes were used, these phenomena did not affect the final concentration of ascorbic acid. However, Assiry et al. (2003) found that during ohmic heating of a buffer solution of pH 3.5, the power, the temperature and the NaCl content affected the degradation rate of ascorbic acid. According to these authors, electrode reactions and electrolysis products may influence both, the reaction mechanism and the kinetics parameters.

In the present work, despite using platinum electrodes, electrolysis and electrochemical reactions were observed at a low intensity. Gas production appeared to occur above 40 °C. The presence of stainless steel temperature sensors may have contributed to the occurrence of these reactions. Qihua, Jindal, and Van Winden (1993) also observed bubble formation during the heating process probably because of some electrochemical reactions, especially when the orange juice temperature reached 50 °C. According to Gregory (1996), the presence of iron may adversely affect the ascorbic acid retention, catalyzing the degradation pathways involving oxygen. Moreover, studies indicate that gas producing reactions accelerate with increasing electric field strengths (Palaniappan & Sastry, 1991; Qihua et al., 1993); this may explain the results obtained in the present study. A greater degradation of ascorbic acid in acerola pulp is observed using high voltages because electrolysis and metal corrosion increase when high electric fields are applied, producing compounds that catalyze the degradation pathways of ascorbic acid in the presence of oxygen.

3.1.2. Total vitamin C degradation

The initial vitamin C content (C_{VTCi}), the final vitamin C content (C_{VTCf}) and the degradation percentage of each experiment are listed in Table 4. It can be observed from this table that the experiments conducted with higher voltages showed higher vitamin C degradation (D_{VTC}). The maximum value of D_{VTC} was 5% at a voltage

Table 3
Analysis of the perturbation of the response variables (D_{AA} and D_{VTC}) caused by the factors during the ohmic heating process.

Factors	Effect	Standard error	t (3)	p coefficient
D_{AA}				
Mean	6.935	0.022	308.79	0.0000
VT[a]	5.621	0.032	176.70	0.0000
VT^2[a]	−0.419	0.036	−11.74	0.0013
SC[a]	−0.147	0.032	−4.63	0.0190
SC^2	0.109	0.036	3.07	0.0546
$VT \times SC$	0.111	0.045	2.48	0.0895
D_{VTC}				
Mean	2.419	0.101	23.98	0.0002
VT[a]	2.278	0.143	15.95	0.0005
VT^2[a]	1.466	0.160	9.16	0.0028
SC	−0.159	0.143	−1.11	0.3464
SC^2	0.352	0.160	2.20	0.1152
$VT \times SC$	0.194	0.202	0.96	0.4079

[a] Significant at 95% of confidence level ($p < 0.05$).

Table 5
AA/DHA ratio before and after the heat treatment by the ohmic heating process.

Experimental design			$R_{AA/DHA}$ (%) initial		$R_{AA/DHA}$ (%) final	
Exp.	VT (V)	SC (g/100 g)	AA	DHA	AA	DHA
1	132	2.88	98.30	1.70	97.34	2.66
2	188	2.88	98.20	1.80	92.57	7.43
3	132	7.12	98.30	1.70	96.83	3.17
4	188	7.12	98.20	1.80	92.22	7.78
5	160	2.00	98.98	1.02	94.31	5.69
6	160	8.00	98.34	1.66	94.29	5.71
7	120	5.00	98.18	1.82	97.09	2.91
8	200	5.00	98.98	1.02	94.52	5.48
9	160	5.00	98.30	1.70	93.92	6.08
10	160	5.00	98.18	1.82	94.18	5.82
11	160	5.00	98.18	1.82	93.64	6.36
12	160	5.00	98.98	1.02	93.67	6.33

of 200 V. For voltages lower than 160 V, the maximum degradation was 2.7%. Furthermore, the total vitamin C degradation was lower than the ascorbic acid degradation for all experiments.

Table 5 presents the AA/DHA ratios for unpasteurized and pasteurized samples. As can be seen, after pasteurization, the AA/DHA ratio changed; experiments conducted with lower voltages achieved AA/DHA ratios closer to those of the non-pasteurized samples than those conducted with higher voltages. The first oxidation reaction (conversion of AA to DHA) probably happened faster than the subsequent reaction, which converts DHA into DCG, a compound that has no biological activity. This result indicates that, during heat treatment, more AA was oxidized to DHA than DHA was oxidized to DCG. As the compound DHA does exhibit biological activity, the total vitamin C degradation was lower than the ascorbic acid degradation. However, it is noteworthy that only AA has anti-oxidant activity and DHA is a pro-oxidant compound that can be easily converted into AA in the human body (Gregory, 1996).

The statistical analysis for D_{VTC}, presented in Table 3, shows that only the linear and the quadratic effects of VT were significant for D_{VTC} at a 95% confidence level. VT positively influenced D_{VTC}, indicating that an increase of VT caused an increase in D_{VTC}. It is also possible to observe that higher VT promotes higher D_{VTC}, independent of the solids content of the pulp.

3.2. Pasteurization by conventional process

Pulps with solids content ranging between 2 and 8 g/100 g were pasteurized using a conventional heating process. The ascorbic acid and the vitamin C contents of pasteurized (P) and non-pasteurized (NP) acerola pulp samples are presented in Table 6. The NP pulp showed a total vitamin C content of 9.39 mg per 100 g of dry

Table 4
Initial and final vitamin C content and the degradation percentage obtained after the ohmic heating process.

Exp.	VT (V)	SC (g/100 g)	C_{VTCi} (mg/100 g, b.s.)	C_{VTCf} (mg/100 g, b.s.)	D_{VTC} (%)
1	132	2.88	9.09 ± 0.04	8.84 ± 0.07	2.71
2	188	2.88	8.85 ± 0.04	8.42 ± 0.06	4.90
3	132	7.12	9.09 ± 0.04	8.88 ± 0.04	2.25
4	188	7.12	8.85 ± 0.04	8.42 ± 0.05	4.82
5	160	2.00	8.88 ± 0.03	8.66 ± 0.07	2.46
6	160	8.00	8.86 ± 0.03	8.65 ± 0.03	2.39
7	120	5.00	8.96 ± 0.03	8.78 ± 0.05	2.00
8	200	5.00	8.88 ± 0.03	8.43 ± 0.05	5.06
9	160	5.00	9.09 ± 0.04	8.85 ± 0.04	2.63
10	160	5.00	8.96 ± 0.03	8.69 ± 0.05	2.15
11	160	5.00	8.96 ± 0.04	8.74 ± 0.06	2.47
12	160	5.00	8.88 ± 0.03	8.74 ± 0.08	2.44

product and ascorbic acid content of 9.28 mg per 100 g of dry product. As can be seen, conventional pasteurization slightly decreased ascorbic acid and vitamin C levels of the samples, with degradation values ranging from 2.87 to 3.70%. The most diluted sample showed the highest degradation: 3.6% for ascorbic acid and 3.70% for vitamin C. Table 6 also shows the percentage of AA and DHA relative to the total content of vitamin C. Both, NP and P samples, showed similar percentages of AA and DHA.

3.3. Ohmic heating versus conventional heating

It can be seen from data presented in Tables 2 and 6 that the ohmic heating experiments carried out at low voltages (<140 V) exhibited AA degradation similar to the conventional heating (0 V). Castro et al. (2004) determined the ascorbic acid degradation kinetics in strawberry pulp under ohmic and conventional heating. The ascorbic acid degradation kinetics for temperatures ranging from 60 to 97 °C was not affected by low values of electric field (<20 V cm^{-1}). Studies performed by Lima et al. (1999) also demonstrated that the nature of the heating, either ohmic or conventional, did not significantly affect the degradation of AA in orange juice. In contrast, in the present study, high voltages promoted greater AA degradation during the ohmic heating when compared to the conventional heating. A similar analysis can be done for the total vitamin C degradation. As observed in Tables 4 and 6, the VTC degradation of experiments with low voltage gradients was smaller than the degradation of the experiments with conventional heating. Furthermore, high voltage gradients caused higher total vitamin C degradation. This behavior can be explained by the increase of electrochemical reactions during high voltage gradient operations which release ions into the liquid that catalyze the oxidation of ascorbic acid. Qihua et al. (1993) observed that during ohmic heating of orange juice, bubbles were produced

Table 6
Initial and final ascorbic acid and vitamin C content and the degradation percentage obtained for experiments conducted by conventional heating.

SC (g/100 g)	C (mg/100 g, b.s.)		$R_{AA/DHA}$ (%)		Degradation (%)	
	AA	VTC	AA	DHA	AA	VTC
NP[a]	9.28 ± 0.03	9.39 ± 0.03	98.92	1.08	–	–
2.00	8.95 ± 0.04	9.04 ± 0.08	99.01	0.99	3.60	3.70
2.88	8.97 ± 0.03	9.07 ± 0.05	98.95	1.05	3.34	3.37
5.00	9.01 ± 0.02	9.12 ± 0.03	98.81	1.19	2.97	2.87
7.12	8.98 ± 0.03	9.09 ± 0.02	98.78	1.22	3.24	3.10
8.00	9.00 ± 0.03	9.11 ± 0.03	98.80	1.20	3.07	2.96

[a] NP − non-pasteurized.

quickly in high voltage gradient operations as a consequence of electrochemical reactions.

Assiry et al. (2003) compared the ascorbic acid degradation kinetics in a buffer solution of pH 3.5 using conventional and ohmic heating. The kinetics of degradation can be described adequately by a first order model for both conventional and ohmic treatments, but unlike conventional heating, the temperature dependence of degradation for some ohmic treatments cannot be represented by the Arrhenius relation. Electrode reactions, electrolysis of the solution, as well as reactions between electrode materials and the electrolysis products may all influence the reaction mechanism and the kinetic parameters. These researchers observed a brown color to the buffer solution, indicating the presence of ferric chloride. Insoluble brown deposits were also observed on the electrode surfaces, indicating the possible formation of iron(III) oxide or ferric chloride.

The results obtained in present study confirm the importance of using either inert coatings on electrodes and sensors or high frequency electric currents to control electrochemical reactions. Further studies of the ohmic heating process should be conducted to achieve a better understanding of the mechanisms involved in the ascorbic acid degradation in the presence of oxygen and metallic ions. In addition, other parameters should be evaluated to compare both heating technologies. For example, studies of the inhibition of enzymatic activity, the destruction of microorganisms and the degradation of other important compounds (such as anthocyanins and phenolic compounds) can be performed to evaluate the potential of the ohmic heating process as an alternative in the heat treatment of foods.

4. Conclusion

This work presents a study regarding total vitamin C and ascorbic acid degradation in acerola pulp during thermal treatment by ohmic and conventional heating. For the ohmic heating technology, the ascorbic acid degradation ranged from 3.08 to 10.63%. The applied voltage and the solids content of the pulp significantly influenced the degradation of the compounds. The voltage gradient had a positive effect, i.e., an increase in the voltage gradient lead to an increase in the AA degradation. The total vitamin C degradation ranged from 2.0 to 5.1%. The vitamin C degradation was influenced only by the linear and the quadratic effects of the voltage.

Ohmic heating, when performed with low voltage gradients, exhibited vitamin C and ascorbic acid degradation similar to conventional heating. However, high voltage gradients increased the degradation of both vitamin C and ascorbic acid. This behavior may be explained by the increase of electrochemical reactions when using high voltage gradients, which can adversely affect the ascorbic acid and catalyze the degradation pathways in the presence of oxygen.

Acknowledgments

Nomenclature

AA	L-ascorbic acid
b.s.	dry basis
C	concentration (mg/100 g)
D	degradation (%)
DCG	diketogulonic acid
DHA	L-dehydroascorbic acid
E	average error (%)
n	number of experimental data points
$R_{AA/DHA}$	AA/DHA ratio
T	temperature (°C)
VT	voltage across the sample (V)
SC	solids content (g/100 g)
$x_1 \ e \ x_2$	represent independent variables in model
y_i	response variables in model

Greek symbols

β_n	coeficientes de regressão multilinear

Subscripts

exp	experimental
pred	predict
i	initial
AA	ascorbic acid
DHA	dehydroascorbic acid
VTC	vitamin C
f	final

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