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Original Article

Effect of plasma and heat treatments on orange juice quality

Efeito de plasma e tratamento térmico na qualidade do suco de laranja

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Abstract

Heat treatment is used in the orange juice industry to neutralize the action of pathogenic microorganisms. However, it can reduce the nutritional value of the juice. Thus, our study assessed the cold plasma treatment as an alternative method against *Escherichia coli* and *Candida albicans* in 'Lima' orange juice. Both, plasma and heat treatments, reduced the amount of *E. coli* in the juice, inactivating 16.72 and 100%, respectively. Plasma did not inactivate *C. albicans*, but heat treatment inactivated 100%. Plasma and heat treatment increased Hue angle and luminosity (more yellowish juice). Plasma reduced vitamin C, carotenoids, and polyphenols content, while increased flavonoids. Heat treatment reduced the carotenoid content. However, neither heat nor plasma treatment altered the antioxidant activity. The plasma treatment reduced the intensity of color (chroma), the soluble solids content and the acidity ratio, total sugars, and the vitamin C content of juice compared to the heat-treated and control juices. Plasma-treated juice showed increased levels of yellow flavonoids, total phenolics and antioxidant activity until the 12th day of storage.

Keywords: bioactive compounds, *Candida albicans*, *Citrus* sp., *Escherichia coli*, non-heat treatment.

Resumo

O tratamento térmico é utilizado na indústria de suco de laranja para neutralizar a ação de microrganismos patogênicos. No entanto, pode reduzir o valor nutricional do suco. Assim, o estudo avaliou o tratamento com plasma frio como método alternativo contra *Escherichia coli* e *Candida albicans* em suco de laranja 'Lima'. Ambos os tratamentos, plasma e calor, reduziram a quantidade de *E. coli* no suco, inativando 16.72 e 100%, respectivamente. O plasma não inativou *C. albicans*, mas o tratamento térmico inativou 100%. Plasma e tratamento térmico aumentaram o ângulo Hue e a luminosidade do suco (tom mais amarelo). O plasma reduziu o conteúdo de vitamina C, carotenóides e polifenóis, enquanto aumentou os flavonóides. O tratamento térmico reduziu o teor de carotenóides. No entanto, nem o calor nem o tratamento com plasma alteraram a atividade antioxidante. O tratamento com plasma reduziu a intensidade da cor (croma), o teor de sólidos solúveis e a razão de acidez, açúcares totais e o teor de vitamina C do suco em comparação com os sucos tratados termicamente e controle. O suco tratado com plasma apresentou maiores teores de flavonóides amarelos, fenólicos totais e atividade antioxidante até o 12º dia de armazenamento.

Palavras-chave: compostos bioativos, *Candida albicans*, *Citrus* sp., *Escherichia coli*, tratamento não-térmico.

1. Introduction

Orange juice is widely consumed around the world, mostly because of its health benefits, such as high nutrition and pleasant aroma (Ni et al., 2020). This juice is an important source of vitamin C, polyphenols, carotenoids, flavonoids, sugars, antioxidant properties and several bioactive compounds (Almeida et al., 2015; Liaquat et al., 2023; Morais et al., 2022). During the processing, the nutritional value as well as the microbiological security of the juice must be maintained in accordance with the standards, as it may also be used as a substrate for microorganisms to grow in, such as bacterial species *Escherichia coli*.

Generally, *E. coli* does not cause harm to human health, but some strains are very pathogenic and may bind to epithelial cells of the intestine and release toxins, causing gastric disorders, known as gastroenteritis (Ramadhianto et al., 2019). The Brazilian Health Regulatory Agency (ANVISA) sets a limit of 10 colony-forming units (CFU) of fecal coliforms (group to which *E. coli* belongs) per milliliter of pasteurized juice (Brasil, 2001). *Candida albicans*, a yeast-like fungus, is another important human pathogen in some cases, especially for people with weakened immune system. Under such circumstances, *C. albicans* causes severe

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diseases and it is hard to treat, which makes it of important concern (Macias-Paz et al., 2023).

The process of pasteurization is the most used treatment in the juice industry, consisting of the application of mild temperatures (under 100 °C) for a few seconds (Chiozzi et al., 2022). Although this process presents high efficacy in the inactivation of pathogenic microorganisms and undesirable enzymes, nutrients loss and changes in the quality of the juice are also produced (Roobab et al., 2022). A study that applied pasteurization and thermosonication in order to assess the quality of tangor juice reported a reduction in ascorbic acid, carotenoids and antioxidant activity (Basumatary et al., 2022).

Due to these constrains, new technologies have been studied and developed to improve the quality of juice, and an increasing interest has been shown for the application of cold plasma. Plasma is formed by electric discharges produced by subjecting liquid or gas to a strong electromagnetic field (Starek et al., 2020). It is comprised of electrons, ions, and both,energized and non-energized, neutral particles (Cherif et al., 2023). For such purpose, it is used a plasma in which the energy of the electrons is much higher than the other species. Since the plasma has a more chemical character and it is obtained at atmospheric pressure is known as cold atmospheric plasma (Ocaña de Jesús et al., 2022).

Previous studies about plasma treatment have demonstrated interesting results for both inactivation of microorganisms and physicochemical characteristics indifferent food products, including juices. The treatment of orange juice inoculated with *Staphylococcus aureus*, *E. coli*, and *C. albicans* with dielectric barrier discharge (DBD) plasma for 12, 8 and 25 s, respectively, showed a 5-log reduction of the microorganisms (Shi et al., 2011). Almeida et al. (2017) also reported that after plasma DBD treatment in prebiotic orange juice the oligosaccharides in the juice were minimally degraded, not affecting its quality, and color and antioxidant activity were preserved. The treatment of orange juice with dielectric barrier discharge plasmas for 2.5, 3.5, 5.0 and 6.0 min with electrical power of 40 W showed a reduction in *Salmonella* spp. colony forming units of 4.47 to 1.00 Log and from 4.00 to 1.00 Log for E. coli (Ocaña de Jesús et al., 2022). Liao et al. (2018) also reported that, after treatment with plasma DBD in apple juice, it had a slight effect on the °Brix, pH, titratable acidity, color values, total phenolic content and antioxidant capacity of this product.

Thus, the present study aimed to assess the physicochemical quality and antioxidant potential of the whole orange juice ('Lima' variety) processed under the conventional thermal treatment and the cold plasma method.

2. Material and Methods

2.1. Microorganisms and inoculating suspensions

The strain ATCC 25922 of *Escherichia coli* was provided by the Laboratório de Bioprocessos from the Universidade Federal do Rio Grande do Norte – UFRN, and *Candida albicans* SC 5314 obtained from the Laboratório Integrado de Biomoléculas from the Universidade Federal do Ceará – UFC. The bacterial suspension of *E. coli* was prepared in Trypticase soy broth, and yeast suspension (*C. albicans*) in potato dextrose broth. After 24 h of incubation under constant stirring and temperature of 36±1 °C (Marconi incubator, model MA-420), bacterial colony-forming units were counted on violet-red bile agar (VRBA) for a concentration of 1.71×10^{10} CFUml^{-1}, and *C. albicans* counted in PDA (3.05×10^{8} CFU ml^{-1}) (Tortora et al., 2012).

2.2. Atmospheric plasma

We used an experimental prototype (unpublished data) developed by the research team of the Laboratório de Processamento de Materiais por Plasma of the Centro Integrado de Inovação Tecnológica do Semi-Árido from the Universidade Federal Rural do Semi-Árido – UFERSA. The device generates plasma DBD at a tension of 14 kV and 400 Hz.

2.3. Treatments

Oranges ('Lima' variety) bought from a local supermarket were sanitized with chlorinated water (100 ppm, 10 min) and squeezed using a kitchen processor to obtain the juice. Sterilization of the juice was performed in autoclave for 15 minutes at 121 °C. With the juice at room temperature, the inoculating suspensions were poured into the juice, separately, and the concentration of each microorganism was adjusted following the methodology described by Montenegro et al. (2002) to 5.86×10^{3} CFU ml^{-1} (*E. coli*) and 1.74×10^{4} CFU ml^{-1} (*C. albicans*). Afterwards, treatments were applied: autoclaved, non-inoculated juice as an absolute control; inoculated juice (negative control); exposition of 5 ml of the inoculated juice to plasma DBD for 1 min in Petri dish (90 mm); and heat treatment for 1 min at 87 °C (water bath) of 50 ml in amber glass bottles (positive control).

Samples of each treatment were then plated on VRBA and potato dextrose agar (PDA) for assessment of colony-forming units of *E. coli* and *C. albicans*, respectively, and incubated on Biological Oxygen Demand (BOD) at 36±1 °C for 24 h (Siqueira, 1995).

A complete randomized experimental design was used, with five replicates. Experimental data were submitted to the non-parametric Kruskal-Wallis test and means compared with Dunn test ($p \leq 0.05$) using the RStudio software (RStudio Team, 2020).

2.4. Physicochemical properties and bioactive compounds during storage

The experiment was conducted in a completely randomized design in a 3x5 split-plot scheme, with five replicates. The plot corresponded to treatments (control, plasma, heat treatment) and subplot to days of storage (0, 4, 8, 12, and 16 days).

The juice from orange fruits ('Lima' variety) underwent both plasma and heat treatments, separately, at the same conditions as described in the previous section. The orange juice was manually removed and deposited in sterilized beakers inside a laminar flow cabinet (Quimis). They were placed in amber glass bottles sterilized by autoclaving. Untreated natural juice was considered as the absolute control.

Samples of each treatment and the control were evaluated for their quality attributes 12 h after the application of treatments (Time-0) and the others were stored in closed bottles at 2±1 °C and relative humidity of 53±3% (Continental TC41 refrigerator) for 16 days, with evaluations being performed every 4 days until the sixteenth day (Figure 1).

We performed analyses for the following traits: color, assessing luminosity (L), chroma (C) and hue angle (H), using a digital colorimeter (CR-400 Chroma Meter, Konica Minolta, Inc., Tokyo, Japan); pH, directly determined by a potentiometer (Tecnal, Piracicaba, SP, Brazil) with automatic temperature adjustment; soluble solids content (SSC), determined by direct refractometry of the juice sample in a digital refractometer with automatic temperature compensation (Palette, Atago, Tokyo, Japan) (Horwitz, 2002); and titratable acidity (TA), obtained by titration with 0.1 N NaOH using 1.0% phenolphthalein as color indicator (Zenebon et al., 2008); and soluble solids content/ titratable acidity ratio (SSC/TA).

Also, total soluble sugars content was determined by the Anthrone method and spectrophotometer reading at 620 nm (Yemn and Willis, 1954); reducing sugars content, using the 3,5-dinitrosalicylic method and spectrophotometer reading at 540 nm (Miller, 1959); carotenoid content, following Higby (1962) methodology (spectrophotometer at 450 nm); yellow flavonoid content, following Francis (1982) methodology (spectrophotometer at 374 nm); total extractable polyphenol content, as described by Larrauri et al. (1997) (spectrophotometer at 700 nm); vitamin C content, using Tillman's solution (Strohecker and Henning, 1967); and antioxidant activity by capturing $ABTS^{\cdot+}$ radical (spectrophotometer at 734 nm) (Rufino et al., 2007).

Data were submitted to two-way analysis of variance and means were grouped by Tukey test ($p \leq 0.05$) in R software (RStudio Team, 2020).

3. Results

3.1. Inactivation of microorganisms

A significant difference ($p < 0.05$) was observed for microbial count population of *E. coli* in the orange juice after plasma treatment, showing a reduced number of CFU ml^{-1} than the negative control, whereas both heat-treated and sterile samples showed to be free from both microorganisms (Table 1). According to the standards set by the ANVISA (Brasil, 2001), only the juice treated with the conventional method (heat) would have been considered good for consumption. There was no significant difference between treatments in juice inoculated with *C. albicans*.

3.2. Physicochemical analysis and bioactive compounds of orange juice in storage

All treatments of juice caused changes in the luminosity values only in the first day of evaluation (the day of treatment), with no changes being reported in the following days of storage (Table 2, Figure 2).

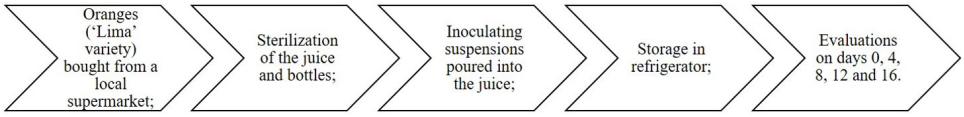

Figure 1. Experiment setup flowchart.

Table 1. CFU of *E. coli* ATCC 25922 and *C.* albicans ATCC SC 5314 in 'Lima' orange juices ubmitted to different treatments.

Treatment	*Escherichia coli*	*Candida albicans*
	CFUml^{-1}	
Non-treated	17.4 (5.86 x 10^4) a	16.4 (1.74 x 10^4) a
Plasma	13.6 (4.88 x 10^3) b	14.6 (1.53 x 10^4) a
Heat	5.5 (0) c	5.5 (0) b
Sterile	5.5 (0) c	5.5 (0) b

Different letters in column represent no significant difference according to Dunn test at 5% probability. Values referring to CFUml^{-1} are rank from the non-parametric analysis (real values in parenthesis).

Table 2. Summary of analysis of variance for luminosity (L), chroma (C), hue angle (°Hue), titratable acidity (TA), and pH of 'Lima' orange juice submitted to different treatments and stored under 2±1 °C for 16 days.

SV	DF	F ratio				
		L	C	°Hue	TA	pH
Treatment (T)	2	11.29**	13.16***	35.53***	52.65***	71.33***
Error a	12					
Storage (S)	4	13.06***	58.81***	45.81***	175.71***	120.4***
T × S	8	2.81*	4.55***	18.09***	51.44***	36.19***
Error b	48					
CV_1%		3.25	11.46	0.64	7.10	2.89
CV_2%		2.88	9.96	0.69	5.69	2.53

SV: source of variation; DF: degrees of freedom; CV: coefficient of variation. *Significant at 5% probability, according to the F-test. **Significant at 1% probability, according to the F-test. ***Significant at 0.1% probability, according to the F-test.

Plasma-treated juice samples showed a significant difference for chroma values only after 8 and 12 days of storage. The hue angle values of all treatments stayed near 100°, in the yellow color range, throughout the whole period of storage. The initial hue angle was higher in heat-treated juice but showed a slight reduction during the storage period, making the yellow color less intense (Figure 2). Samples treated with cold plasma showed the greatest values at the end, where their yellow was most vivid.

Only after 8 days of storage we observed some alterations in the titratable acidity and pH of the treated juices. After 16 days, plasma-tread samples showed lower pH, and consequently greater acidity than control and heat treatment (Figure 3). Similarly, differences in the SSC and SSC/TA ratio were observed only after 8 days of storage, with a reduction occurring in the juice treated with plasma (Table 3, Figure 4).

Total soluble sugars and reducing sugars contents were altered only after the 8th day of storage. However, after 16 days the plasma-treated juice showed similar content of total sugars to the absolute control. The juice under thermal treatment maintained the highest content of total sugars and reducing sugars (Figure 5).

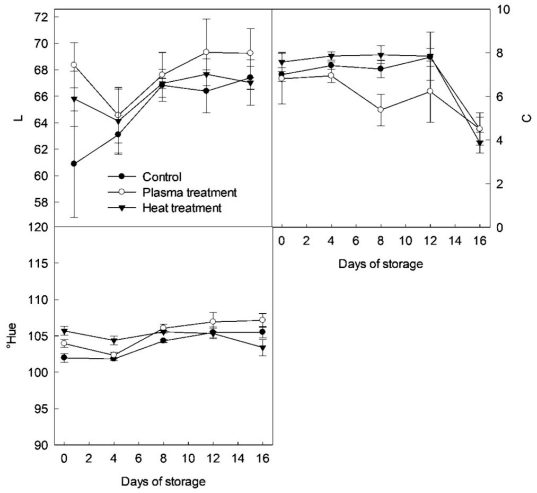

Figure 2. Color as luminosity (L), chroma (C) and hue angle (°Hue) of 'Lima' orange juice submitted to different treatments and stored under 2±1 °C for 16 days.

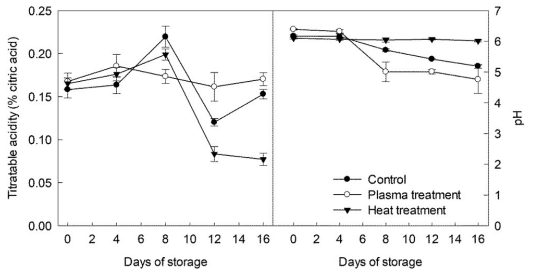

Figure 3. Titratable acidity and pH of 'Lima' orange juice submitted to different treatments and stored under 2±1 °C for 16 days.

Table 3. Summary of analysis of variance for soluble solids content (SSC), soluble solids content/titratable acidity ration (SSC/TA), total soluble sugars content (TSS), and reducing sugars content (RS) of 'Lima' orange juice submitted to different treatments and stored under 2±1 °C for 16 days.

SV	DF	F ratio			
		SS	SSC/TA	TSS	RS
Treatment (T)	2	96.62***	313.67***	19.76***	7.88**
Error a	12				
Storage (S)	4	111.31***	263.66***	118.25***	55.95***
T × S	8	41.75***	114.49***	3.88**	2.65*
Error b	48				
CV_1%		1.32	7.57	7.03	5.35
CV_2%		1.10	6.83	6.03	6.83

SV: source of variation; DF: degrees of freedom; CV: coefficient of variation. *Significant at 5% probability, according to the F-test. **Significant at 1% probability, according to the F-test. ***Significant at 0.1% probability, according to the F-test.

There were no significant differences in Vitamin C between factors treatment and storage. The values for the absolute control, plasma- and heat-treated juices were 35.09, 28.90, and 32.29 mg100g^{-1}, respectively, with the plasma treatment showing the lowest values of all treatments. During the storage period, we observed a reduction in vitamin C from 42.68 in the day of processing to 27.53 mg100g^{-1} after 16 days of storage (Table 4, Figure 6).

There was a degradation of carotenoids in heat- and plasma-treated juices. No significant difference for carotenoid content after 4, 8, and 16 days of storage was seen. In general, both plasma and heat treatments caused the same level of loss in carotenoids (Figure 6).

A higher polyphenol content was observed in the absolute control and heat-treated juices at the day of processing and after 4 days of storage, in comparison to plasma treatment. After 8 and 12 days, the juice under plasma treatment showed an increase in polyphenols, significantly higher than the other treatments. A small reduction of polyphenols content was observed after 16 days of storage (Figure 6). Similar behavior as for the plasma effect was observed for the antioxidant activity after 16 days of storage. The juice under plasma treatment had a reduction in the antioxidant activity when compared to the absolute control. It was also possible to observe that in the day of the processing the antioxidant activity in heat- and plasma-treated juice was higher (3.72 and 3.37 µM Troloxg^{-1}, respectively) (Figure 6).

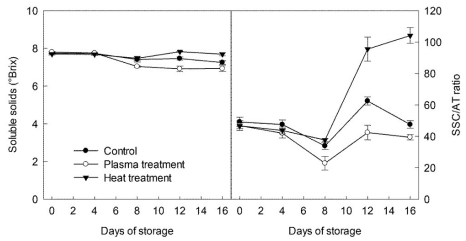

Figure 4. Soluble solids content and soluble solids content/titratable acidity (SSC/TA) ratio of 'Lima' orange juice submitted to different treatments and stored under 2±1 °C for 16 days.

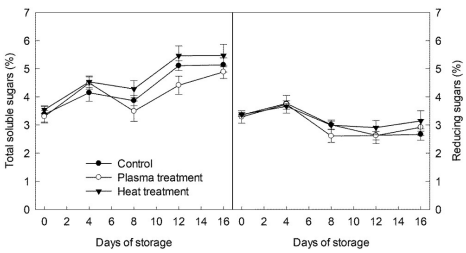

Figure 5. Total soluble sugars and reducing sugars content of 'Lima' orange juice submitted to different treatments and stored under 2±1 °C for 16 days.

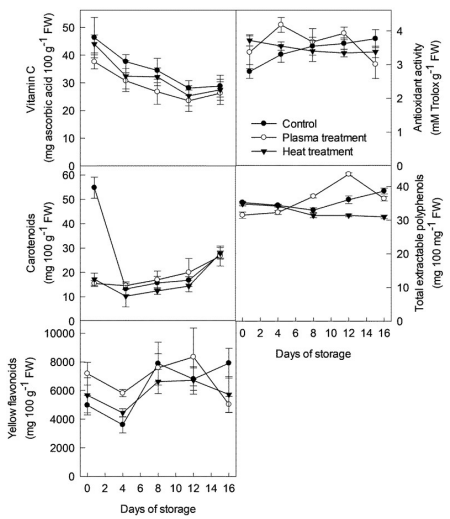

Figure 6. Vitamin C, antioxidant activity, carotenoids, total extractable polyphenols, and yellow flavonoids in 'Lima' orange juice submitted to different treatments and stored under 2±1 °C for 16 days.

Table 4. Summary of analysis of variance for Vitamin C (VitC), antioxidant activity (AA), carotenoids (Carot), total extractable polyphenols (TEP), and yellow flavonoids (Flav) of 'Lima' orange juice submitted to different treatments and stored under 2±1 °C for 16 days.

SV	DF	F ratio				
		VitC	AA	Carot	TEP	Flav
Treatment (T)	2	15.89***	2.92^{ns}	102.26***	272.45***	5.68*
Error a	12					
Storage (S)	4	39.23***	6.29***	80.51***	77.26***	18.23***
T × S	8	0.703^{ns}	11.93***	47.94***	148.43***	5.88***
Error b	48					
CV_1%		11.93	9.53	12.10	1.67	16.11
CV_2%		12.82	7.18	15.62	1.86	16.24

SV: source of variation; DF: degrees of freedom; CV: coefficient of variation. *Significant at 5% probability, according to the F-test. ***Significant at 0.1% probability, according to the F-test. ^{ns}Non significant.

4. Discussion

Cold plasma treatment significantly reduced the population of *E. coli* in the juice as compared to untreated juice (Table 1). Although plasma was less effective than heat treatment, our study opens perspectives for the use of this technique that has been tested against several microorganisms in many products. Klämpfl et al. (2012) treated spores of *C. albicans* with plasma (10 kV_{pp}, 1 kHz, under atmospheric pressure) in petri dishes for 30 s and observed about 4-log inactivation. Xiong et al. (2010) observed the effect of cold plasma at 8 kV, 9 kHz and helium gas at a rate of 2 L min^{-1} on *C. albicans*, showing a 99.9% of inactivation after 8 min in closed Petri dishes, while in open Petri dishes the inactivation was reduced to a few fractions, similarly to our results (also treated in open Petri dishes). The differences verified between the data obtained in this work and the works discussed here may be due to the differences between the technical specifications of the plasma devices used. The inactivation of fungi by treatment with cold plasma is given by the destruction and deformation of structures, and the degeneration and oxidation of proteins and DNA molecules in the cytoplasm (Xiong et al., 2010; Ye et al., 2012; Kang et al., 2014; Lu et al., 2014).

Taking into consideration the large reduction of microbial population after plasma treatment in previous studies, the small effect in our study may have been caused by a combination of different factors such as the power our device compared to others in previous works, the input of gas flow into the system, distance between the sample and plasma, and amount of treated sample.

Regarding juice quality, the color of the juice was not significantly affected by the treatments used. Although some values of hue angle (H) and luminosity (L), color parameters, were significantly different during storage, it does not cause a difference in juice color that can be perceived by the consumer. Kovačević et al. (2016b) also observed color change in pomegranate juice treated with plasma generated with argon gas (2.5 kV and 25 kHz). Such changes are influenced by the duration of the treatment, volume of the sample, and rate of gas flow into the system.

From eight days of storage, pH, titratable acidity (TA), soluble solids content (SSC), and SSC/TA ratio started to vary among treatments. At 16 days, the plasma-treated juice presented higher acidity and lower pH (Figure 3). Our results are consistent with Xiang et al. (2018), who observed a reduction of pH and an increase in acidity in apple juice treated with plasma DBD for 40 to 200 s at 90 W. However, SSC did not change over time. Differently, Shi et al. (2011) reported no alteration in pH and acidity in orange juice treated with plasma DBD (30 kV, 60 kHz) for 5 to 20 s.

Furthermore, total soluble sugars (TSS) and reducing sugars (RS) did not vary among treatments. From eight days of storage, the plasma-treated juice had lower TSS and RS, while the heat-treated juice had the highest contents (Figure 5). Almeida et al. (2015) have also observed the effect of plasma treatment DBD (70 kV, 50 Hz, under the presence of atmospheric air) on the levels of reducing sugars, where they reported reduction of reducing sugar fructose after 60 s of treatment. Such effect of the plasma after a small period under treatment was not observed in the present study, probably because the frequency and tension used (14 kV, 400 Hz) were different from the previous study.

The vitamin C degradation observed in the plasma-treated juice is probably associated with a greater exposition to the atmospheric air, since the juice in the open Petri dish formed a surface-layer of 9 cm diameter during the treatment. This may be due to the high concentration of oxygen in the air that degrades the vitamin C by activating oxidase enzymes (Shi et al., 2011). However, previous studies on the effect of plasma on vitamin C are very inconsistent. Shi et al. (2011) analyzed orange juice treated with plasma DBD (20 kV and 60 kHz) in open Petri dishes and no significant reduction in the vitamin C content was reported. However, Almeida et al. (2017), reported an increase in vitamin C when treating 20 ml of orange juice with plasma DBD (70 kV, 50 Hz, atmospheric air) for 1 min.

There was a degradation of carotenoids in heat- and plasma-treated juices. No significant difference for carotenoid content after 4, 8, and 16 days of storage was seen. In general, both plasma and heat treatments caused the same level of loss in carotenoids (Figure 6). Both plasma and heat treatments reduced carotenoids content in orange juice. The photooxidation of carotenoids is mainly influenced by oxygen and light (Dutra et al., 2012), which were inevitable during the processes. Another possible factor related to the degradation of carotenoids is the heat (87 °C) used in one treatment. Dutra et al. (2012), when treated mandarin orange juice at 88 °C for 30 s (like what was used in this study) observed a reduction of approximately 11% in carotenoid content.

A higher polyphenol content was observed in the absolute control and heat-treated juices in the day of processing and after 4 days of storage, in comparison to plasma treatment. After 8 and 12 days, the juice under plasma treatment showed an increase in polyphenols, significantly higher than other treatments. A small reduction of polyphenol content was observed after 16 days of storage (Figure 6). Similar behavior as for the plasma effect was observed for the antioxidant activity after 16 days of storage. The juice under plasma treatment had a reduction in the antioxidant activity when compared to the absolute control. It was also possible to observe that in the day of the processing the antioxidant activity in heat- and plasma-treated juice was higher (3.72 and 3.37 μM Trolox g^{-1}, respectively) (Figure 6). Almeida et al. (2015) treated 20 mL of orange juice supplemented with oligosaccharide with plasma DBD (70 kV, 50 Hz, atmospheric air) and observed a reduction in phenolic compounds after 15, 30, 45, and 60 s. Distinct results were reported by Herceg et al. (2016) as an increase of phenolic compounds were seen in pasteurized (80 °C, 2 min) pomegranate juice and treated with plasma (argonium gas, 2.5 kW, 25 kHz). Such discrepancy in the polyphenol content found in the present work and by these other authors may be related to the difference of compounds found on different fruits (Kovačević et al., 2016a).

Our results showed that cold plasma treatment is promising for the inactivation of microorganisms in orange juice, besides maintaining better organoleptic properties as compared to heat treatment. However, further studies should focus on finding adequate treatment duration, volume of sample to be treated, rate of gas flow into the system to improve capacity of the treatment to improve the treatment's ability to inactivate microorganisms and to maintain beneficial compounds in juice.

Heat and plasma treatments reduce the *Escherichia coli* population in orange juice. Plasma treatment is not effective in inactivating *Candida albicans*, while heat treatment inactivates 100%. Plasma treatment reduces chroma (always being below the other treatments throughout the days of storage), soluble solids content/ titratable acidity ratio, total soluble sugars, and vitamin C content in orange juice, as compared to heat- and autoclaved-treat juices. This fact can end up harming the acceptance of the product by the consumer market, since it can change its flavor. However, plasma-treated orange juice shows increased levels of yellow flavonoids, total extractable polyphenols, and antioxidant activity ($ABTS^{+}$) until the 12 days of storage as compared to heat- and autoclaved-treated juices.

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