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Effect of Atmospheric Cold Plasma on the Aroma of Pineapple Juice: Improving Fresh and Fruity Notes and Reducing Undesired Pungent and Sulfurous Aromas

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Abstract: Pineapple aroma is characterized by several esters, which confers its fresh and fruity aroma. However, high concentrations of methyl hexanoate and thioesters bring an undesired pungently sweet aroma and sulfurous notes to pineapple juice. This study investigates the chemical effects of cold plasma on the aroma compounds and descriptors of pineapple juice, evaluating the effects of plasma on its esters and thioesters. Dielectric barrier discharge plasma was applied to pineapple juice, varying the excitation frequency (50 to 1000 Hz) and processing time (10 to 20 min) at constant voltage (20 kV). Plasma treatment induced successive demethylation of esters and the conversion of methyl esters into ethyl esters. Thioesters showed to be more stable under plasma treatment. Proper setting of plasma operating conditions enabled an improvement in the fresh and fruity descriptors of pineapple juice, a reduction of its undesired pungently sweet aroma, but an increase in the influence of sulfurous descriptors. Plasma treatment at 50 Hz reduced the undesired aromas of pineapple while maintaining its fresh and fruity descriptors.

Keywords: dielectric barrier discharge plasma; *Ananas comosus*; quality; aroma; food chemistry

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1. Introduction

Juice flavor is key to consumer acceptance and preference [1]. Conventional thermal processing of fruit juices is the most widely used technology for preserving and extending their shelf life. However, the drawbacks of this protocol are well known and include the degradation of thermosensitive compounds and loss of aroma, flavor, and nutritional quality [2–4]. Industrial thermal processing of pineapple juices often present undesirable aroma notes described as "cooked vegetables" and "intense artificial aroma", which are due to the production of thermal degradation compounds such as methyl butanoate, ethyl 2-methylbutanoate, methyl hexanoate, and ethyl hexanoate, and by the formation of off-flavors such as methional, and dimethyl di-, tri-, and tetrasulfide. These are the main reasons for the relatively low use of pineapple as a raw material in the industrialized juice market [5–7].

Cold plasma (CP) is a non-thermal technology with great potential for fruit product applications. Positive results have been achieved in terms of sanitization and preservation, removing pesticides and mycotoxins, and reducing allergens in different food groups [8,9]. Depending on the process conditions, it is possible to observe better retention and, in some cases, the increase of bioactive compounds [10]. All these effects result from chemical reactions between the reacting plasma species and the compounds from the food matrix. Due to the high complexity and diversity of food compounds, the changes induced by cold plasma application are variable and strongly dependent on the food matrix composition [11]. Thus, the effects of cold plasma on food properties, quality, and composition must be studied throughly.

Greater emphasis has been given to studies on the mechanisms of plasma action and chemical changes on different macro and micro molecules of fruit juices, including sugars, amino acids, lipids, vitamins, carotenoids, phenolics, anthocyanins, and other bioactive compounds [12–14]. Despite all the information available about plasma, the impact of this technology on aromas still needs to be better understood. Studies investigating the nature of changes in volatile profiles are scarce and predominantly attribute the changes to reactive oxygen species (ROS) and reactive nitrogen species (RNS), presenting no or simplistic statements about the reaction mechanisms [15]. More comprehensive studies on the changes in the volatile composition of tomato [16], orange [17], camu-camu [18], and apple [19] juices treated by atmospheric cold plasma were reported. However, they still cover only a fraction of the many volatile compounds in fruit juices.

A recent approach to plasma applications demonstrates the possibility of aroma modulation [17,18,20]. In other words, applying plasma in fruit products could reduce unpleasant aromas, accentuate desired aromas, and produce new notes for a new perception experience [18,21]. Reactions induced by dielectric barrier discharge plasma can be used to reduce off-flavors in orange juice, converting the undesired a-terpineol to limonene or sabinene, which gives the characteristic aroma of this beverage [17]. In camu-camu pulp, the changes in the volatile compounds directly affected the aroma profile, increasing or decreasing the woody, citrus, and herbal notes of the pulp fragrance, conferring different aromas to the juice and conferring new perception experiences [21].

Pineapple juice has a wide variety of esters, aldehydes, furanone, alcohols, acids, hydrocarbons, and sulfur-containing compounds [22–24]. However, its volatile composition is mainly characterized by several esters and thioesters. Compounds that have yet to be thoroughly studied regarding how plasma application affects them. This work aimed to identify and discuss the chemical pathways of the reactions induced by dielectric barrier discharge (DBD) plasma application in pineapple juice and to evaluate how these chemical changes alter the aroma profile of juice rich in esters and thioesters. Furthermore, this work is intended to evaluate the best operating condition that can increase the desirable fruity aroma, while controlling the undesired sulfurous notes and the pungent aroma derived from a high concentration of methyl hexanoate.

2. Materials and Methods

2.1. Materials

Pineapples (*Ananas comosus*) were purchased from a local fruit distributor (Fortaleza, Brazil). The fruits were peeled, the core was removed, and the flesh was processed in a domestic juicer centrifuge (Philips model RI1858/50) to obtain the juice.

2.2. Plasma Processing

Cold plasma processing was carried out using an Inergiae model PLS0130 plasma generator. The generator was coupled to a DBD plasma system comprised of two 8 cm diameter aluminum electrodes and two acrylic plates (5 mm thick) acting as dielectric barriers. An acrylic Petri dish containing 20 mL of pineapple juice was placed in the gap (15 mm) between the electrodes. The Petri dish was 55 mm in diameter and 14 mm in height, and the sample height in the Petri dish was 8.4 mm. Plasma treatment was carried out for 10 and 20 min at frequencies of 50, 500, and 1000 Hz, and at a fixed voltage at 20 kV. The plasma discharge occurred in open space (the sample was not sealed inside any vessel) using atmospheric air as the gas source at ambient temperature (25 °C). These operating conditions were chosen based on prior studies that indicated that these frequencies and processing times result in significant changes in aroma profiles [20,25,26]. All experiments were carried out in triplicates.

2.3. Chromatographic Analysis

The volatile compounds of processed and unprocessed pineapple juice were determined and measured by Solid Phase Microextraction (SPME) coupled with GC-MS analysis. The volatile components were extracted using an aliquot of 5.0 mL of pineapple juice that was added to a 10 mL vial containing 2 g of sodium chloride, which was equilibrated at 40 °C for 10 min. A fiber coated with 50/30 µm of Divinylbenzene/Carboxene/ Polydimethylsiloxane (DVB/CAR/PDMS) was used to extract and absorb the volatile compounds in the vial headspace. The extraction was carried out at 40 °C for 30 min without agitation. After extraction, the volatiles were directly desorbed in the gas chromatograph (Thermo Scientific, model ISQ) coupled to a mass spectrometer (Thermos, Waltham, MA, USA, model Trace Ultra ISQ). The carrier gas was helium at 1.0 mL/min. The temperature ramp on the GC-MS started at 40 °C, held for 4 min, raised to 80 °C at 2.5 °C/min, raised to 110 °C at 5.0 °C/min, raised to 250 °C at 10 °C/min, and held after reaching 250 °C for 1 min. The injector temperature was set at 230 °C, the MS transfer line at 250 °C, and the MS ion source at 200 °C. A DB-5MS column was used for the separation of the volatile compounds. The components were identified by comparing their retention indexes (RI) and mass spectra with software libraries (NIST, Gaithersburg, MD, USA and Wiley, Hoboken, NJ, USA). The peak areas were used to calculate the relative contents of volatile compounds. All analyses were carried out in triplicates.

2.4. Reactive Oxygen Species Determination

The relative amount of reactive oxygen species for each plasma condition was determined following the methods described by Lankone et al. [27] for hydroxyl radicals, Ovenston and Rees [28] for hydrogen peroxide, and Magnani et al. [29] for superoxide anion, single oxygen, and ozone. All analyses were carried out in triplicates.

2.5. Odor Activity Values (OAV) and Aroma Correlation

To evaluate the contribution of each volatile compound to aroma composition, the odor activity value was calculated based on the mass fraction of each compound divided by its odor threshold in water [30]. The values for odor threshold in water were obtained in the literature [31–36]. The compounds in pineapple juice were grouped according to their primary and secondary odor description based on information in the "The Good Scent Company" database [37]. The five main odor descriptors that give pineapple juice its characteristic aroma were plotted: fruity, sulfurous, fatty, waxy, and floral.

3. Results

3.1. Changes in Volatile Compounds Profile Induced by DBD Plasma

Table 1 shows the main volatile compounds of pineapple juice identified in our study and their relative abundance (% *w*/*w*) under each treatment condition. The pineapple juice was characterized by several esters (71.4%), two thioesters (14.8%), and other minor compound groups (acids, aldehydes, furans, and hydrocarbons) (13.8%). Methyl hexanoate (53.2%), methyl 3-(methylthio)propanoate (12.5%), ethyl hexanoate (10.0%), and methyl 2-methyl butanoate (7.8%) were the main compounds in the untreated pineapple juice.

Mass balance calculations demonstrated that DBD plasma application considerably reduced the concentration of esters, particularly esters with high carbon numbers, such as methyl hexanoate, ethyl hexanoate, and methyl octanoate. Mass balance calculations with the ester compounds indicated that plasma induced the abstraction of methyl units from the esters, continuously decreasing its number of carbons. Figure 1 shows a putative chemical pathway for plasma-induced changes in ester compounds. The abstraction of methyl units occurred mainly with esters with more than six carbons, while compounds with lower carbon numbers showed to be less affected by methyl abstraction. Thus, the final product showed an increase in the mass fraction of ethyl acetate, methyl butanoate, and methyl 2-methyl butanoate. Methyl group abstraction has been previously reported in some cold plasma applications, such as in branched furans and pyrazines [20] and starch [38].

Table 1. Mass fraction of volatile compounds (% w/w) of pineapple juice subjected to dielectric barrier discharge plasma under different operating conditions. Number of replicates = 3.

	Control	Dielectric Barrier Discharge Plasma Conditions (Frequency and Time)					
		50 Hz 10 min	50 Hz 20 min	500 Hz 10 min	500 Hz 20 min	1000 Hz 10 min	1000 Hz 20 min
Ethyl acetate	3.48 ± 0.18	5.10 ± 0.20	6.95 ± 0.28	5.95 ± 0.24	2.31 ± 0.09	12.14 ± 0.49	12.20 ± 0.49
Methyl butanoate	1.70 ± 0.09	4.52 ± 0.18	0.81 ± 0.03	5.27 ± 0.21	1.02 ± 0.04	1.38 ± 0.06	0.79 ± 0.03
Methyl 2-methyl butanoate	7.84 ± 0.40	8.32 ± 0.33	3.70 ± 0.15	9.70 ± 0.39	9.81 ± 0.30	9.75 ± 0.39	5.14 ± 0.21
Ethyl 2-methyl butanoate	1.54 ± 0.08	1.82 ± 0.07	1.17 ± 0.05	2.13 ± 0.09	1.66 ± 0.07	2.09 ± 0.08	1.22 ± 0.05
Methyl hexanoate	53.16 ± 2.68	23.91 ± 0.96	11.65 ± 0.47	27.88 ± 1.12	27.53 ± 1.10	28.69 ± 1.15	18.68 ± 0.75
Ethyl hexanoate	10.00 ± 0.50	6.45 ± 0.26	1.98 ± 0.08	7.52 ± 0.30	8.33 ± 0.33	8.64 ± 0.35	8.42 ± 0.34
Methyl 3-(methylthio) propanoate	12.55 ± 0.63	16.14 ± 0.65	38.29 ± 1.53	18.82 ± 0.75	21.39 ± 0.86	16.97 ± 0.68	21.06 ± 0.84
Ethyl 3-(methylthio) propanoate	2.28 ± 0.04	3.71 ± 0.15	8.31 ± 0.33	4.33 ± 0.17	5.09 ± 0.20	4.36 ± 0.17	6.27 ± 0.25
Methyl octanoate	2.44 ± 0.11	0.42 ± 0.02	0.00 ± 0.00	0.49 ± 0.00	0.42 ± 0.02	0.29 ± 0.01	0.24 ± 0.01
1.3.5-Undecatriene	0.56 ± 0.04	0.45 ± 0.02	0.00 ± 0.00	0.52 ± 0.00	1.49 ± 0.06	1.71 ± 0.07	1.07 ± 0.04
Octanoic acid	0.03 ± 0.01	0.47 ± 0.02	1.43 ± 0.06	0.54 ± 0.02	1.06 ± 0.04	1.12 ± 0.04	1.68 ± 0.07
Ethyl octanoate	0.07 ± 0.01	1.71 ± 0.07	0.14 ± 0.01	2.00 ± 0.02	1.27 ± 0.05	0.85 ± 0.03	0.28 ± 0.01
Decanal	0.00 ± 0.00	0.00 ± 0.00	0.94 ± 0.04	0.00 ± 0.00	1.79 ± 0.07	0.00 ± 0.00	0.00 ± 0.00
5-Hydroxymethyl-2-furaldehyde	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.66 ± 0.03	0.00 ± 0.00	0.11 ± 0.01
Phenethyl acetate	0.17 ± 0.01	0.62 ± 0.02	0.99 ± 0.04	0.72 ± 0.03	0.88 ± 0.04	0.66 ± 0.03	1.19 ± 0.05
5-Butyldihydro-2(3H)-furanone	0.17 ± 0.01	0.44 ± 0.02	0.91 ± 0.04	0.51 ± 0.02	0.60 ± 0.02	0.48 ± 0.02	0.74 ± 0.03
Methyl linoleate	0.98 ± 0.01	1.42 ± 0.06	2.18 ± 0.09	1.66 ± 0.07	1.72 ± 0.07	1.56 ± 0.06	1.42 ± 0.03

The abundance of thioesters did not change significantly during cold plasma application. However, due to the decrease in ester content, the mass fraction of thioesters in the volatile profiles increased. After plasma processing, the ratio between methyl 3-(methylthio)propanoate and ethyl 3-(methylthio)propanoate decreased. Mass balance calculations with the thioesters evidenced that part of the methyl radicals abstracted from the esters reacted with the methyl thioester producing ethyl thioesters (Figure 1). The reaction could also be observed with ester compounds, where the ratio between methyl and ethyl esters also decreased. This grafting reaction was observed mainly at high plasma generation frequencies (1000 Hz).

The reactive oxygen species formed in the pineapple juice due to plasma treatment were evaluated and presented in Table 2. The characterization used the available methods used to evaluate radical scavenging capacity, and as such, the results represent the amount of reactive species absorbed by the juice. The methods calculate the scavenging capacity of the solution during the treatment and do not allow the determination of the concentration of the reactive species. Thus, the scavenging capacities were normalized between 0 and 1, with 1 representing the highest amount of reactive species absorbed by the juice.

Plasma treatment at 50 Hz induced the formation of the highest amount of hydroxyl radical in the juice while inducing a low generation of superoxide anion. The treatment at 500 Hz presented the highest amounts of hydrogen peroxide and superoxide anion and a high hydroxyl radical content. Plasma at 1000 Hz presented high hydrogen peroxide content and the lowest content of hydroxyl radical and superoxide anion.

The greatest changes observed in the volatile profile of pineapple juice occurred in the treatment carried out at 500 Hz, which presented the highest content of reactive oxygen radicals. Although no hydrolysis and oxidation products were observed, these reactive species may have induced the formation of free radicals in the volatile compounds that resulted in the abstraction of the methyl group observed in the reaction pathway presented in Figure 1.

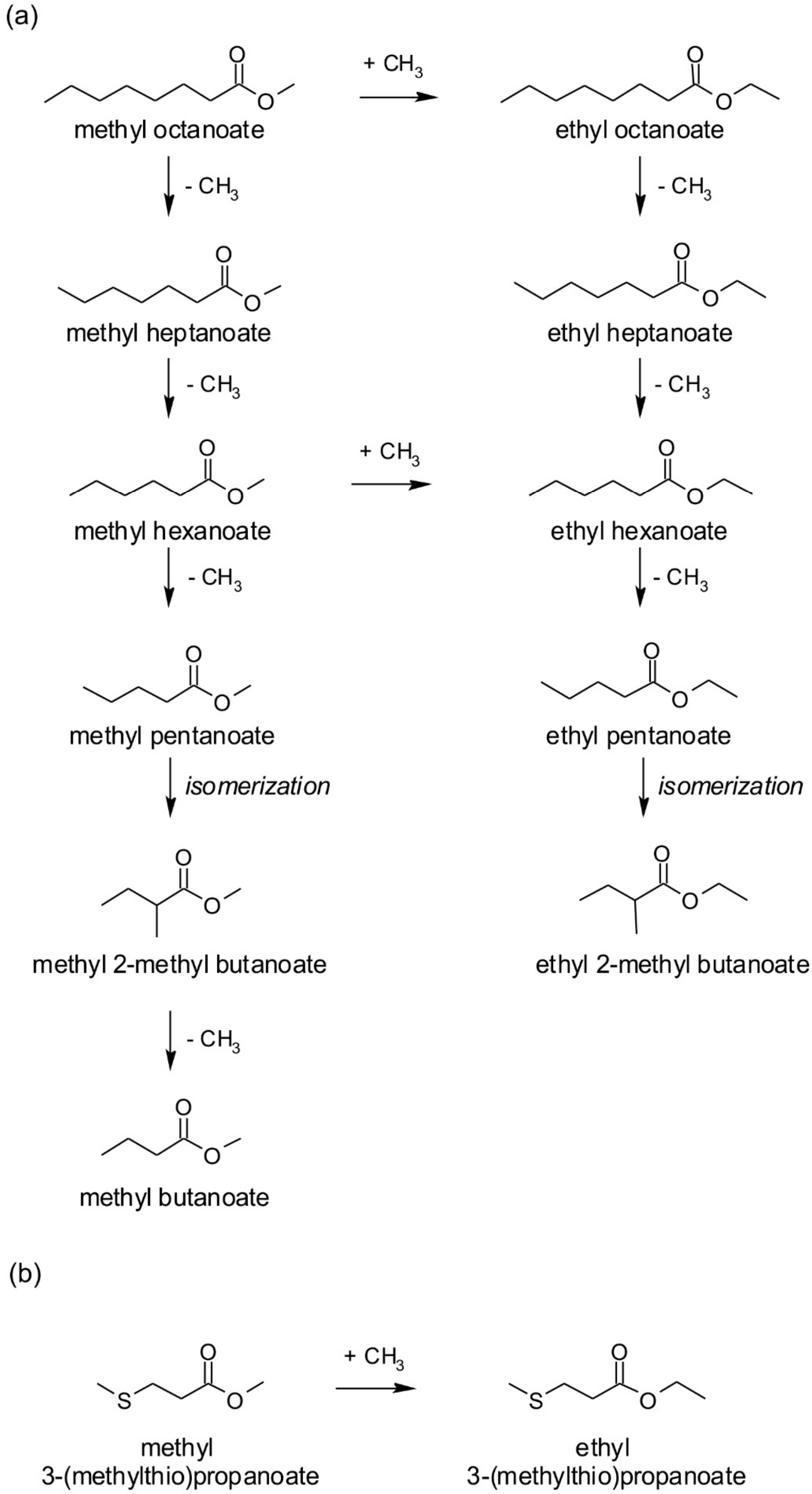

Figure 1. Plasma-induced reactions in ester (**a**) and thioester (**b**) compounds from pineapple aroma.

Table 2. Reactive oxygen species formed in pineapple juice subjected to dielectric barrier discharge plasma under different operating conditions. Results are presented in normalized values. Number of replicates = 3.

Frequency (Hz)	Hydroxyl Radical	Hydrogen Peroxide	Superoxide Anion
50	1.0 ± 0.0	0.9 ± 0.1	0.3 ± 0.1
500	0.9 ± 0.1	1.0 ± 0.0	1.0 ± 0.0
1000	0.4 ± 0.1	1.0 ± 0.0	0.2 ± 0.1

3.2. Changes in the Aroma Profile Induced by DBD Plasma

The changes in the volatile compounds profile induced by plasma treatment directly impact the pineapple juice aroma. Thus, it is essential to understand how the changes in volatile composition affect the sensory quality of the juice. Current knowledge of odor thresholds and descriptors of individual compounds can produce a satisfactory aroma profile of the juice without requiring trained sensory panelists, as has been done for many years in the perfume industry [36].

Table 3 presents the odor description notes and the odor threshold value of the main volatile compounds in the pineapple juices. The most relevant descriptive notes for the aroma composition of the pineapple juices were fruity, sulfurous, fatty, and waxy. To discuss the main changes in the aroma of the treated juices, each processing condition was compared with the descriptive notes profile of the natural juice (untreated). Significant changes in the aroma profile could be noted in the conditions studied.

Table 3. Primary and secondary odor descriptors of the main volatile compounds found in pineapple juice and their odor thresholds in water.

	Primary Odor Description	Secundary Odor Description	Odor Threshold (mg/L Water)
Ethyl acetate	ethereo	-	25
Methyl butanoate	fruity	apple/ sweet	0.076
Methyl 2-methyl butanoate	fruity	ethereal	0.00025
Ethyl 2-methyl butanoate	fruity	sharp/sweet	0.0003
Methyl hexanoate	fruity	ethereal	0.084
Ethyl hexanoate	fruity	sweet	0.001
Methyl 3-(methylthio)propionate	sulfurous	-	0.180
Ethyl 3-(methylthio)propanoate	sulfurous	-	0.007
Methyl octanoate	waxy	-	0.200
1.3.5-undecatriene	fruity	fresh/green	0.00002
Octanoic acid	fatty	-	0.910
Ethyl octanoate	waxy	-	0.005
Decanal	aldehydic	-	0.030
5-Hydroxymethyl-2-furaldehyde	fatty	-	100
Phenethyl acetate	floral	-	0.650
5-Butyldihydro-2(3H)-furanone	fatty	-	0.007
Methyl linoleate	ethereo	-	2

Plasma processing at a low frequency (50 Hz) promoted changes mainly in the fruity descriptor of the pineapple juice aroma. Although the characteristic esters from pineapple juice changed after processing, the total contribution of the fruity descriptor remained similar after a short processing time (10 min). However, at longer processing times (20 min), the significance of the fruity descriptor decreased but remained as the primary descriptor (Figure 2). The reduction in the significance of the fruity descriptor was caused by the decrease in the concentration of methyl 2-methyl butanoate (−52%), ethyl 2-methyl butanoate (−24%), methyl hexanoate (−78%), and ethyl hexanoate (−80%).

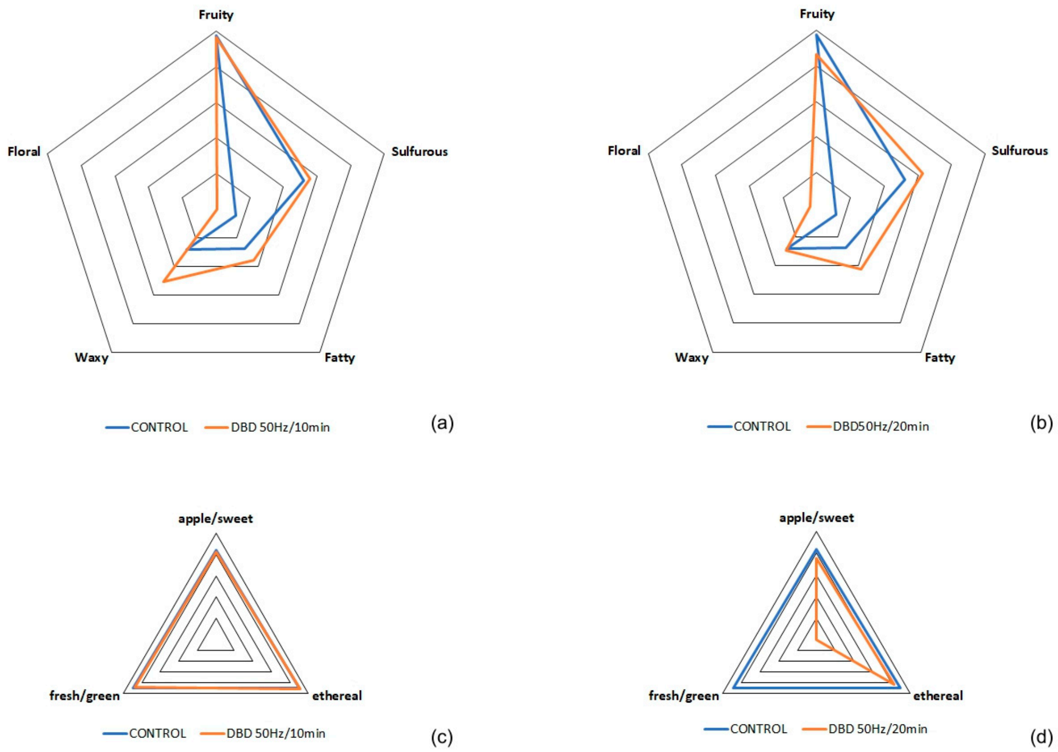

Figure 2. Aroma descriptors radar for pineapple juice subjected to dielectric barrier discharge plasma application: (**a**,**b**) OAV of the untreated, 50 Hz/10 min, and 50 Hz/20 min samples; (**c**,**d**) OAV of the secondary notes of the fruity descriptor for the untreated, 50 Hz/10 min, and 50 Hz/20 min samples.

The secondary descriptive notes of the fruity aroma were also evaluated since the fruity aroma is highly dominant in pineapple juice. The natural pineapple juice presented a balanced profile on the fruity secondary descriptors, among sweet, ethereal, and fresh notes. At low frequencies and long exposure time (50 Hz/20 min), the samples lost the fresh note, and the ethereal note dominated the fruity aroma. This impact was due to the absence of the 1,3,5-undecatriene after plasma treatment. This compound was reported in some studies as an important aroma contributor to the pineapple odor in many cultivars [37,38].

The sulfur descriptor increased at low frequency and long processing time (50 Hz/20 min) because of the increase in the mass fraction of methyl 3-methyl(thio)propanoate and ethyl 3-methyl(thio)propanoate. The fatty descriptor became more intense after low-frequency cold plasma application in all processing times, which was caused by a significant increase in the mass fraction of 5-butyldihydro-2(3H)-furanone and octanoic acid. The increase was more significant at longer processing times.

The waxy aroma increased after 10 min of exposure at low frequency due to the increase in ethyl octanoate content (>100%). Further processing of the juice (50 Hz/20 min) reduced the intensity of the waxy aroma due to the significant reduction in methyl and ethyl octanoate concentrations, the two compounds that give the waxy aroma to pineapple juice. According to the reaction pathway observed for esters (Figure 1), methyl and ethyl octanoates decayed into esters with shorter chain lengths, which present fruity notes.

Extended processing of pineapple juice (20 min) resulted in the appearance of an aldehydic aroma note, which emerged from the formation of decanal, which was formed from the scission of the small amounts of fatty methyl esters in the juice [18]. The OAV of the aldehydic aroma was insignificant compared to the other OAVs of the five main aroma descriptors, and the presence of this note did not compromise the sensory quality of the juice.

Under a mid-range frequency (500 Hz), the impact of the fruity descriptor in the aroma increased. The secondary descriptive notes of the fruity aroma showed a high increase of the fresh note at an extended processing time (20 min). The sweet and ethereal notes remained at the same levels as the natural juice. The increase in the fresh note was related to the rise in the concentration of the 1,3,5-undecatriene (Figure 3).

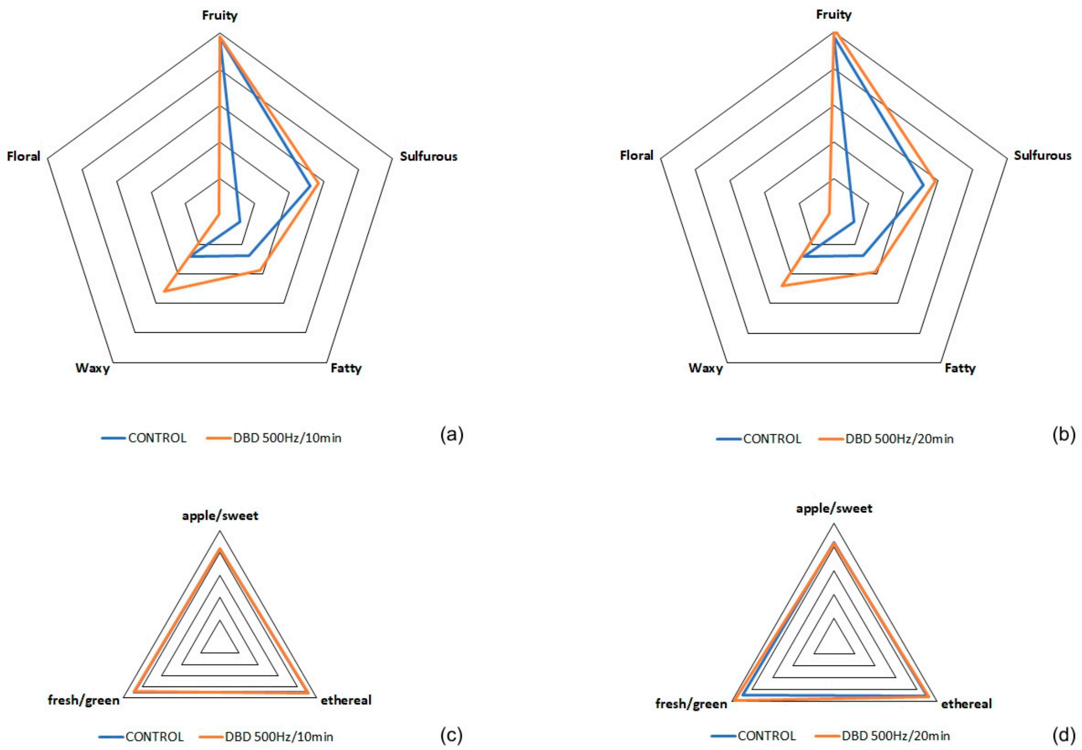

Figure 3. Aroma descriptors radar for pineapple juice subjected to dielectric barrier discharge plasma application: (**a**,**b**) OAV of the untreated, 500 Hz/10 min, and 500 Hz/20 min samples; (**c**,**d**) OAV of the secondary descriptive notes of the fruity aroma for the untreated, 500 Hz/10 min, and 500 Hz/20 min samples.

The results obtained from low frequency (50 Hz) and mid-range frequency (500 Hz) shows the importance of the excitation frequency in cold plasma applications, since the changes induced on the aroma profile were significantly different between these two frequencies. Such differences have also been perceived for other fruit juices, such as camu-camu [18], orange [17], and coffee [20] subjected to plasma treatment.

The changes in volatile compounds after plasma treatment at 500 Hz were more intense than in the other frequencies, probably due to the higher content of reactive oxygen radicals formed during processing. The changes were marked by the increase in the mass fraction of thio compounds and the decrease in the mass fraction of short-chain esters.

The increased mass fraction of thio compounds, mainly methyl 3-methyl(thio)propanoate and ethyl 3-methyl(thio)propanoate, had a direct effect on pineapple juice aroma with an increase of 113% in the sulfurous notes after 20 min of treatment.

The fatty and waxy aromas also increased in the 500 Hz plasma treatment. The fatty aroma became 258% more intense due to the significant increase in the concentration of 5-butyldihydro-2(3H)-furanone and octanoic acid in the first 10 min of treatment. Further increase in the fatty aroma was observed after 20 min of treatment due to the formation of 2-furaldehyde-5-hydroxymethyl. The increase in ethyl octanoate intensified the waxy aroma. In fresh pineapple juice, the strength of the waxy aroma is given by equal contributions of ethyl- and methyl-octanoate. In the plasma-treated juice, methyl octanoate was converted into ethyl octanoate (Figure 1), and the strength of the waxy aroma was caused mostly by the contents of ethyl octanoate.

The fruity aroma remained as the main aroma descriptor of pineapple juice despite the reduction in short-chain esters concentration observed in the 500 Hz plasma-treated juice.

The changes observed in the short-chain esters profile resulted in the reduction of esters with high odor thresholds and the increase of esters with low odor thresholds. Therefore, the sum of the OAVs of the fruity-flavored compounds did not change significantly.

At high frequency (1000 Hz), the impact of the fruity descriptor in the aroma also increased, but much less (14%) than at mid-range frequency (69%). The secondary descriptive notes of the fruity aroma followed the same trend observed at mid-range frequency, presenting an increase in the fresh note and a decrease in the ethereal note. The increase in the fresh note was related to the rise in the concentration of the 1,3,5-undecatriene (Figure 4).

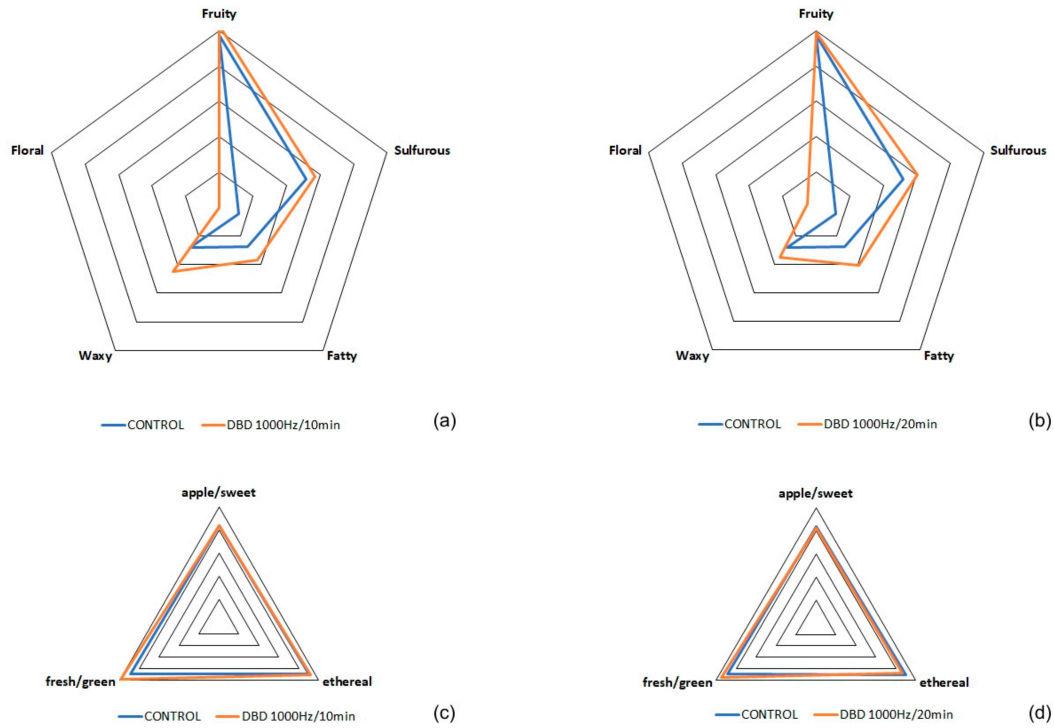

Figure 4. Aroma descriptors radar for pineapple juice subjected to dielectric barrier discharge plasma application: (**a**,**b**) OAV of the untreated, 1000 Hz/10 min, and 1000 Hz/20 min samples; (**c**,**d**) OAV of the secondary descriptive notes of the fruity aroma for the untreated, 1000 Hz/10 min, and 1000 Hz/20 min samples.

The plasma treatment at 1000 Hz also increased the OAVs of the floral, waxy, fatty, and sulfurous aromas of pineapple juice. Among these increased OAVs, the increase in the sulfurous descriptor was the most relevant. At this operating condition, the fruity to sulfurous OAV ratio decreased from 190.1 (natural) to 85.4 (plasma-treated), indicating the higher contribution of the sulfurous aroma that can compromise the odor balance in pineapple juice. For this reason, the operation at 1000 Hz would not be recommended for pineapple juice processing.

The OAV of the fatty and waxy aroma descriptors increased following the same trend observed for the plasma-treated juice at mid-range frequency. A positive effect of the plasma treatment at 500 and 1000 Hz was the reduction of the methyl hexanoate concentration, a compound that gives a pungent sweet aroma to pineapple and is considered an off-flavor for some customers [23].

Evaluating the aroma descriptors attained at the three frequencies tested, the treatment carried out at 500 Hz enhances the fresh and fruity aroma characteristics of pineapple juice. The operation at 50 Hz (the lowest frequency tested) is not recommended for this juice because it significantly reduces its fresh and fruity aroma and increases the fruity-to-sulfurous ratio. However, the operation at 50 Hz, if carried out for less than 10 min, may decrease the pungent note of methyl hexanoate without compromising the remaining influence of the descriptors.

4. Conclusions

Plasma treatment induced successive demethylation of esters and the conversion of methyl esters into ethyl esters. Thioesters showed to be more stable under plasma treatment. The changes in the volatile chemical composition resulted in changes in the aroma. Different operating conditions enable an improvement in the fresh and fruity descriptors, a reduction of the pungently sweet aroma of methyl hexanoate, or an increase of the influence of sulfurous descriptors. Low frequencies reduce the pungently sweet aroma of methyl hexanoate when the process is carried out for less than 10 min, while longer processing reduces the freshness of the juice. Mid-range frequency improves the fresh and fruity descriptors of pineapple juice, while high frequencies increases the influence of sulfurous descriptors. Therefore, it is possible to induce intentional changes in key compounds of pineapple juice, modulating its aroma to adapt the sensory juice profile to consumer preferences.

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