



## Influence of the cultivation system in the aroma of the volatile compounds and total antioxidant activity of passion fruit

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### ABSTRACT

The aim of this study was to investigate the influence of the cultivation system on the volatile composition of the passion fruit and to determine the odoriferous contribution of the compounds for the aroma of the organic and conventional fruit, besides to assess the total antioxidant activity. The volatile compounds were isolated from dynamic headspace, separated by high-resolution gas chromatography and the odoriferous contribution to the passion fruit aroma was evaluated using the OSME technique. Total antioxidant activity was determined using the ABTS radical reaction. The organic and conventional passion fruit showed similar volatile profile, although some differences occurred. Ethyl 2-propenoate, 2-methyl-1-propanol, diethyl carbonate and ethyl hexanoate were threefold higher in the organic fruit while butyl acetate, hexanal, *cis*-3-hexenyl acetate and *trans*-3-hexenyl butanoate were threefold higher in the conventional fruit. Hexanoate and acetate esters, and saturated alcohols described as fruity, sweet, citrus and passion-fruit aroma showed the highest odorific intensity in the organic fruit. Furthermore, *trans* and *cis*-3-hexenyl acetate and alpha-copaene, alpha-terpineol, D-limonene, *trans*-beta-ocimene and delta-cadinene had higher contribution to the organic passion fruit aroma. On the other hand, unsaturated alcohols, beta-myrcene and beta-linalool described as grass, sulfur-like and passion-fruit aroma were higher in the conventional fruit. The organic passion fruit showed higher levels of total phenolic compounds and total antioxidant activity than the conventional fruit, suggesting that the cultivation system influenced the production of antioxidant bioactive compounds.

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### 1. Introduction

Organic foods have been gaining popularity among health and environment conscious consumers who prefer foods of high nutritional and sensory quality without chemical residues used in production agriculture (IFOAM, 2010). The world market of organic foods has an annual turnover of around US\$ 30 billion. The Brazilian market represents about US\$ 250 million, but this is growing at 25% a year, particularly passion fruit, mango, guava, papaya, banana, grape, strawberry and citrus fruit. Most Brazilian organic foods are exported to Europe, the United States, Canada and Japan. Seventy percent of the organic producers in the country are small producers and most of the certified organic growers are concentrated in the southeast and southern regions, especially in the state of São Paulo (IBD, 2010).

Brazil is the largest producer and consumer of passion fruit in the world. The economically most important form of passion fruit (*Passiflora edulis* Sims f. *flavicarpa* Deg.) is responsible for 95% of the cultivation area, grown by organic or conventional systems. Passion fruit is consumed as in natura fruit and used to produce industrialized juice and other fruit products (Meletti & Maia, 1999), being very appreciated mainly because of the exotic, flowery and fruity aroma.

Many studies have reported that organic products have superior nutritional and sensory quality than conventional products (Amaro & Monteiro, 2001; Asami, Hong, Barrett, & Mitchell, 2003; Carbonaro & Mattera, 2001; Dani et al., 2007; Santos & Monteiro, 2004). It can be attributed to the favored synthesis of bioactive compounds from the secondary metabolism in response to the stressful conditions inherent to the organic cultivation system, such as the lack of use of pesticides and fertilizers, among others. This may lead to important changes in the physicochemical characteristics and in the composition of the volatile compounds, such as terpenes and esters, important for the characteristic aroma of fruit (Briskin, 2000; Engelberth, 2006).

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The influence of the variety, post-harvest period and processing on the passion fruit volatile profile has been reported (Narain, Almeida, Galvão, Madruga, & Brito, 2004; Pino, 1997; Shibamoto & Tang, 1990; Winterhalter, 1991). The importance of the volatile compounds derived from the terpenes, from the breakdown of carotenoids and from the sulfur compounds for the characteristic aroma of passion fruit has also been reported (Engel & Tressl, 1991; Werkhoff, Güntert, Krammer, Sommer, & Kaulen, 1998).

Even though a wide range of studies have been published on the volatile compounds of yellow passion fruit, few have made use of the GC–O technique (gas chromatography–olfactometry) to identify which odoriferous compounds are important for the aroma. The olfactometric technique OSME allows the odoriferous importance of each volatile compound to be determined by associating chromatographic peaks to the odor intensity responses of a selected and trained panel of judges, so that the impact of each volatile compound on the overall aroma of the fruit can be assessed (Le Guen, Prost, & Demaimay, 2000; McDaniel, Miranda-Lopez, Watson, Micheals, & Libbey, 1990; Van Ruth & O'Connor, 2001). The passion fruit produced by conventional system has been analyzed by CG–O–AEDA (Jordán, Goodner, & Shaw, 2002) and CG–O–OSME (Jales et al., 2005) techniques. However, no research has been published using these methods to relate the passion fruit volatile composition to the cultivation system.

The aim of this study was to investigate the influence of the cultivation system on the volatile composition of the passion fruit and to determine the odoriferous contribution of the compounds for the aroma of the organic and conventional fruit, besides to assess the total antioxidant activity.

## 2. Material and methods

### 2.1. Material

Organic and conventional yellow Afruvec passion fruit (*P. edulis* Sims f. *flavicarpa* Deg.) were obtained from producers in the Southwest region of the State of São Paulo, Brazil, during the 2006 harvest. The organic fruits, certified at the Biodynamic Institute (IBD), São Paulo, Brazil, were cultivated in Paulistânia, SP (22°34'42" S and 49°24'10" W, 645 m altitud) and the conventional fruits in Bauru, SP (22°19'18" S and 49°04'13" W, 526 m altitud). Organic and conventional passion fruit (40 kg) from the same stage of development was harvested and immediately taken to the laboratory (Amaro & Monteiro, 2001; De Marchi, Monteiro, Benato, & Silva, 2000). The fruits were screened, inspected and washed. The pulp was separated from the seeds and peel, which were discarded. The clean pulp was packed directly in hermetically sealed 250 mL glass flasks and stored in a freezer at –18 °C until the analysis.

### 2.2. Reagents

All reagents used were of GC-analytical grade, and were supplied by Merck (Darmstadt, Germany) or J. T. Baker (Philipsburg, USA). The volatile standards used were from Sigma–Aldrich (St. Louis, USA) or Fluka (Steinheim, Germany).

### 2.3. Total antioxidant activity and physicochemical analysis

The total antioxidant activity of the organic and conventional passion fruit pulp was analyzed using the ABTS radical reaction (Rafino et al., 2010), and total phenolic compounds by the Folin–Ciocalteu reaction (Asami et al., 2003; Macoris, Janzantti, & Monteiro, 2008). Soluble solids (°Brix), pH, titratable acidity, ascorbic acid and total and reducing sugar were determined according to AOAC (1998). Three replicate analyses were carried out

for the pulp of each cultivation system. The ratio (rate of soluble solids and titratable acidity) was calculated.

### 2.4. Isolation of the volatile compounds

The volatile compounds were isolated by dynamic headspace (Franco & Rodriguez-Amaya, 1983). Three hundred grams of passion fruit pulp were placed in a 1000 mL flask with NaCl (30 g/100 g), used to avoid the enzymatic degradation of the volatile compounds. The volatile compounds from the headspace of the passion fruit pulp were sucked by vacuum (79.99 mm Hg) at room temperature (25 °C) into a porous polymer trap (15 cm × 0.3 cm of 100 mg of a 150–180 µm Porapak Q, Waters Associates, Milford, USA) for 2 h and then eluted with 300 µL of dichloromethane (Macoris, Janzantti, Garruti, & Monteiro, 2011). Three replicates of the organic and conventional yellow passion fruit pulps were analyzed by GC–FID.

### 2.5. Gas chromatographic analysis

The volatile compounds of the passion fruit pulp were analyzed using a Shimadzu 2010 (Kyoto, Japan) high-resolution gas chromatograph (GC) equipped with a DB-Wax column (30 m length, 0.25 mm i.d., 0.25 µm film thickness) from J & W Scientific, (Folsom, USA), maintained at 40 °C for 10 min and then programmed to rise to 200 °C at 3 °C/min, where it was held for 10 min. The splitless mode injector (2 µL) was maintained at 200 °C and the flame ionization detector (FID) at 250 °C. Hydrogen was the carrier gas at a flow rate of 1.3 mL/min.

### 2.6. Gas Chromatography–Mass Spectrometry (GC–MS)

The volatile compounds of the passion fruit pulp were identified by GC–MS analysis. A Shimadzu 2010 GC equipped with a Shimadzu 2010 Mass Detector (Kyoto, Japan) was used to obtain the mass spectra. The column and temperature programs were the same as those used for the chromatographic analysis. The DB-Wax column (30 m length, 0.25 mm i.d., 0.25 µm film thickness) was maintained at 40 °C for 10 min and then programmed to rise to 200 °C at 5 °C/min, where it was held for 10 min. Helium was the carrier gas at a flow rate of 1.3 mL/min. The injector and detector temperatures were 230 °C and 240 °C, respectively. Mass spectra were obtained by electron impact at 70 eV, in the scanning mode, *m/z* range from 35 to 350.

The volatile compounds were identified from the mass spectra and literature data (NIST vers. 1.7). Retention indices were determined using a homologous series of normal *n*-alkanes, C<sub>10</sub>–C<sub>26</sub>. The identities were confirmed by comparison of the relative retention indices and odor of the compounds with those of authentic standards and/or from literature sources (Acree & Arn, 2004; Jales et al., 2005; Jordán et al., 2002; Macoris et al., 2011).

### 2.7. Gas Chromatography–Olfactometry (GC–O)

The odoriferous contribution of the volatile compounds of the pulp of organic and conventional passion fruit was analyzed by OSME (Da Silva, Lundhal, & McDaniel, 1994). Each volatile compound in the headspace was separated on a capillary column and assessed by selected and trained judges, the data being collected and analyzed by SCDTI, a time-intensity data acquisition system developed jointly by the School of Food Engineering and School of Electrical Engineering and Institute of Computing of the State University of Campinas-UNICAMP, Brazil (Da Silva, 1999).

GC was used for the separation of the volatile compounds, under the same conditions as those employed to analyze the volatile

profile of the pulp. For the olfactometric analysis, the equipment was modified, so that the GC column was disconnected from the FID and connected to a flow splitter installed in the chromatograph oven, which directed the emerging volatile compounds via an inactive column (without stationary phase) to the nose of the judge. The splitter also introduced a carrier gas, to make up the volume of the column and ensure the compounds were delivered quickly from the system. The ODO II system from SGE (Texas, USA) was used to lead the outlet gas stream to the nose of the judge and to warm the tube surrounding the inactive column. This system includes a device to introduce moistened air into the outlet stream, to minimize the discomfort caused by drying of the nasal mucosa during the olfactometric tests.

The intensity of the aroma perceived by the judge for each volatile compound was recorded on a hybrid 10-point scale, anchored at 0, 5 and 10 points, representing “none”, “moderate” and “extreme or strong”, respectively. The judge was prompted to use the scale displayed on a computer screen, while each compound was being eluted from the GC column, to record the intensity and describe the odor. Each session lasted 30 min and each judge took two sessions to complete each replicate test.

The olfactometric analysis was carried out in triplicate by five selected and trained female judges, aged between 22 and 35 years. The chosen judges showed good discrimination ( $p \leq 0.005$ ) and repeatability ( $p > 0.05$ ) when analyzing the intensity of characteristic aroma of the passion fruit (Macoris et al., 2011).

The aroma intensity data collected by the SCDTI program from each judge were united to generate an individual aromagram, which represented the average of three replicates. Therefore, only the data referring to aromas recorded by the judge in at least 50% of the replicates were used to construct the aromagram.

At the end of the session, the individual average aromagrams were combined into a consensus aromagram by the panel of judges. Only those data associated with aromatic compounds recorded by at least two of the five judges were included. As before, the consensus intensity of each aroma was obtained by summing the intensities described by the judges who detected that aroma and dividing by their number. The qualitative description of each aroma was elaborated from the descriptions produced by all the judges.

To ensure that the chromatographic data and compound identities were correctly related to the olfactometric data, the retention indices of each aroma described in the consensus aromagram were calculated. Furthermore, the judges' description of the aroma of each compound was checked against their published descriptions (Acree & Arn, 2004; Jales et al., 2005; Jordán et al., 2002; Sampaio, Garruti, Franco, Janzantti, & Da Silva, 2011).

## 2.8. Statistical analysis

Physicochemical data were subjected to analysis of variance (one-way ANOVA) and Tukey's test, employing the Statistical Analytical System, SAS<sup>®</sup> 6.12. The olfactometric data were processed with Microsoft Excel.

## 3. Results and discussion

### 3.1. Physicochemical characteristics of the passion fruit pulp

The results for total antioxidant activity, total phenolic compounds and physicochemical characteristics of the pulp of organic and conventional passion fruit are shown in Table 1. The organic fruit pulp showed higher titratable acidity ( $p \leq 0.05$ ), reducing sugars ( $p > 0.05$ ), total sugars ( $p > 0.05$ ), ascorbic acid ( $p \leq 0.05$ ), total phenolic compounds ( $p \leq 0.05$ ) and total antioxidant activity. The conventional passion fruit pulp showed higher

values for soluble solids ( $p \leq 0.05$ ), pH ( $p > 0.05$ ) and ratio ( $p \leq 0.05$ ). The higher levels of total phenolic compounds and total antioxidant activity in the organic pulp suggest that the cultivation system influenced the production of antioxidant bioactive compounds (Carbonaro & Mattera, 2001; Dani et al., 2007).

The Brazilian legislation establishes values of 2.5 g of citric acid/100 mL; glucose content lower than 18.0 g/100 mL, 11 °Brix and pH values between 2.7 and 3.8; as standards for identity and quality of passion fruit pulp (BRASIL, 2000). All the physicochemical parameters (Table 1) conformed to the requirements of the Brazilian legislation, indicating that the pulps were suitable to be industrialized and consumed, and to be employed in the present assessment of the profile and odoriferous importance of the headspace volatile compounds.

### 3.2. Profile of volatiles of the passion fruit pulp

Eighty-four compounds were detected in the headspace of the passion fruit pulp, sixty-four of which were identified by mass spectra, retention indices and odor descriptions in comparison with those of volatile standards, comprising 96% of the chromatogram area (Table 2 and Fig. 1). The identified volatile compounds consisted of esters (31 compounds), alcohols (11), terpenes (10), aldehydes (5), ketones (5), an aromatic hydrocarbon (1) and a sulfur compound (1).

The esters, well-known as major contributors to the characteristic fruity and sweet aromas of a wide variety of fruits, have also formed the largest group of volatile compounds in other studies on passion fruit, while the alcohols, which are important for the flowery, green and herby aromas, are the second largest group (Shibamoto & Tang, 1990; Winterhalter, 1991). The hexanal, octanal and benzaldehyde are worth mentioning for their particular contribution to the green and citrus aromas of various fruits (Werkhoff et al., 1998). Volatile compounds from the breakdown of non-volatile precursors, such as the terpenes beta-linalool, alpha-terpineol, beta-myrcene, alpha-copaene, D-limonene, *trans*-beta-ocimene, *cis*-beta-ocimene and alpha-cubebene (Table 2), among others, are also considered to be important to the green aroma of the passion fruit (Pino, 1997).

The only sulfur compound identified in this study was dimethyl disulfide (Table 2). Others have been detected in minimum amounts in passion fruit, by means of an electron-capture detector, a specific detector for sulfur, nitrogen and halogen compounds, including 3-mercaptohexanol and 3-mercaptohexyl butanoate (Engel & Tressl, 1991).

In both the organic and conventional passion fruit, the most abundant headspace volatile compounds were ethyl butanoate, vinyl benzene and hexanol. They showed minor differences between the relative area percentage of the chromatographic peaks of the organic and conventional passion fruit (Table 2). Ethyl

**Table 1**  
Physicochemical parameters of the organic and conventional passion fruit pulps.

Parameters	Organic	Conventional
Titratable acidity (g citric acid/100 mL)	4.32 <sup>a</sup>	3.81 <sup>b</sup>
Soluble solids (°Brix)	13.43 <sup>b</sup>	14.71 <sup>a</sup>
pH	3.36 <sup>a</sup>	3.53 <sup>a</sup>
Ratio	3.19 <sup>b</sup>	3.85 <sup>a</sup>
Reducing sugars (g glucose/100 mL)	4.78 <sup>a</sup>	4.71 <sup>a</sup>
Total sugars (g glucose/100 mL)	5.26 <sup>a</sup>	5.23 <sup>a</sup>
Ascorbic acid (mg/100 mL)	5.62 <sup>a</sup>	3.63 <sup>b</sup>
Total phenolic compounds (mg galic acid/100 mL)	528.93 <sup>a</sup>	415.66 <sup>b</sup>
Total antioxidant activity (µmol Trolox/100 mL)	112.21	53.44

Means with the same letter in the same line did not significantly differ in the Tukey test ( $p \leq 0.05$ ). Ratio = soluble solids/titratable acidity.

butanoate has also been reported as the majoritary volatile compound in passion fruit (Winterhalter, 1991). Although the organic and conventional fruit volatile profiles were similar, there were significant differences in the percentage area of certain compounds. It is worth mentioning that the organic pulp showed a threefold peak area for ethyl 2-propenoate, 2-methyl-1-propanol, diethyl carbonate and ethyl hexanoate, whereas butyl acetate, hexanal, *cis*-3-hexenyl acetate and *trans*-3-hexenyl butanoate had a threefold peak area greater for the conventional fruit pulp (Table 2).

### 3.3. CG-O-OSME of the passion fruit pulp

The consensus aromagrams for organic and conventional passion fruit pulps are shown in Fig. 2. The sensory panel detected 58 odor compounds in both fruit pulps. The volatile compounds that brought odoriferous contributions to the aroma of the fruit showed intensities ranging from 0.49 (unidentified compound - IR 2247 -described as having a rubber and toasty aroma) and 0.36 (benzaldehyde, described citrus and sweet) up to 9.12 (ethyl hexanoate, described as sweet and fruity) and 9.38 (ethyl butanoate, described as a sweet and strawberry), for the organic and conventional fruit, respectively (Table 3). On the aromagram, the volatile compounds whose intensity lays in the upper half of the hybrid scale (>5.0 points), between “moderate” and “extreme or strong”, were considered to be of great importance to the passion fruit aroma. Those of intensity between 3.0 and 4.9 were described as making a moderate odoriferous contribution, while those between 0.1 and 2.9 were of low contribution.

The volatile compounds that were most important to the passion fruit aroma were the same in both the conventional and the organic fruit, in spite of some differences in intensity. Thus, the esters propyl acetate (“passion fruit”, sour and flowery), diethyl carbonate (synthetic, plastic and metallic) and ethyl hexanoate (sweet and fruity) had stronger intensity in the organic pulp aroma. The esters methyl butanoate (“passion fruit”, sweet, strawberry and fruity), ethyl butanoate (sweet and strawberry) and ethyl octanoate (grass and earthy), as well as the alcohol *cis*-3-hexen-1-ol (“passion fruit”, sulfur-like and grass), were more intense in the conventional passion fruit (Table 3).

The volatile compound *cis*-3-hexenyl acetate, alpha-copaene, *cis*-3-hexenyl hexanoate and alpha-terpineol, all described as “passion fruit” aroma, were of low intensity yet still present in the headspace of both organic and conventional fruits, but with higher intensity in the organic fruit. On the other hand, the compounds 2-pentanone and the unidentified peak 2 (IR <1000), described as “passion fruit”, were only perceived in the conventional fruit pulp, at low intensity (Table 3).

Hexanal (sweet, citrus and green), 1-butanol (sharp, flowery and sweet), D-limonene (eucalypt, lemon grass and citrus), *trans*-beta-ocimene (herb, peel and sweet) and butyl hexanoate (flowery and green) showed moderate intensity aroma in the organic, but low strength in the conventional fruit. The opposite was found for ethyl *cis*-3-hexenoate (leaf, grass, plastic and burnt) and hexyl propanoate (green banana and strawberry). The terpenes beta-myrcene (sweet and citrus) and beta-linalool (lemon, citrus and sour) contributed with moderate intensity to the aroma of passion fruit of both cultivation systems, but they were more intense in the conventional fruit.

*Trans*-3-hexenyl acetate (fruity and citrus), amyl hexanoate (stink and stink bug), hexyl hexanoate (solvent, stink and sulfur-like), benzyl acetate (citrus, flowery and green) and delta-cadinene (citrus and flowery) contributed weakly to the aroma of the pulp from both organic and conventional passion fruit, albeit with higher intensity in the organic fruit. Octanal (sweet, fruity,

**Table 2**

Volatile compounds identified in the organic and conventional passion fruit pulps.

Peak	Rt <sup>d</sup>	Compound	Organic <sup>e</sup>	Conventional <sup>e</sup>
7	<1000	Propyl acetate <sup>a</sup>	0.10	0.16
8	<1000	3-methylbutanal <sup>b</sup>	0.48	0.73
9	<1000	Methyl butanoate <sup>a</sup>	0.25	0.14
10	<1000	Ethyl 2-propenoate <sup>c</sup>	0.82	nd-0.05
11	<1000	2-hexanone <sup>b</sup>	nd-0.05	nd
12	1006	Methyl 2-methylbutanoate <sup>b</sup>	tr-0.05	nd-tr
13	1009	2-methylpropyl acetate <sup>a</sup>	0.33	0.40
14	1013	Methyl 3-methylbutanoate <sup>b</sup>	0.43	0.72
16	1033	Ethyl butanoate <sup>a</sup>	56.69	56.31
17	1042	2-methyl-3-buten-2-ol <sup>c</sup>	0.87	1.28
18	1045	Ethyl 2-methylbutanoate <sup>b</sup>	0.44	0.49
19	1069	Dimethyl disulfide <sup>b</sup>	0.07	0.19
20	1072	Butyl acetate <sup>a</sup>	0.36	1.34
21	1077	Hexanal <sup>a</sup>	nd	0.26
22	1096	2-methyl-1-propanol <sup>b</sup>	0.53	0.07
23	1099	Diethyl carbonate <sup>b</sup>	2.09	0.19
25	1129	3-methylbutyl acetate <sup>b</sup>	0.57	0.77
26	1142	Ethyl pentanoate <sup>b</sup>	0.05	0.12
27	1157	3-heptanone <sup>b</sup>	0.10	0.10
28	1158	1-butanol <sup>b</sup>	0.19	0.32
29	1161	Alpha-phellandrene <sup>b</sup>	nd-0.05	0.08
30	1167	Beta-myrcene <sup>a</sup>	1.47	1.19
31	1178	2-heptanone <sup>b</sup>	0.10	0.22
32	1182	Heptanal <sup>b</sup>	0.09	tr-0.06
33	1183	D-limonene <sup>a</sup>	0.11	0.27
34	1188	Isoamyl alcohol <sup>b</sup>	0.19	tr
35	1190	Butyl butanoate <sup>a</sup>	0.79	0.79
38	1216	<i>Trans</i> -beta-ocimene <sup>b</sup>	0.65	0.49
39	1217	Ethyl hexanoate <sup>a</sup>	2.23	0.50
40	1239	Vinyl benzene <sup>b</sup>	15.60	13.04
41	1253	<i>Cis</i> -beta-ocimene <sup>b</sup>	1.66	2.28
44	1265	Pentanol <sup>b</sup>	0.14	nd-0.10
45	1276	Hexyl acetate <sup>a</sup>	1.17	2.75
46	1282	Octanal <sup>a</sup>	0.08	tr
47	1303	Ethyl <i>trans</i> -3-hexenoate <sup>b</sup>	0.28	0.48
49	1308	Ethyl <i>cis</i> -3-hexenoate <sup>b</sup>	0.05	0.09
50	1311	<i>Trans</i> -3-hexenyl acetate <sup>b</sup>	0.09	0.22
51	1319	<i>Cis</i> -3-hexenyl acetate <sup>b</sup>	0.46	2.19
52	1333	6-methyl-5-hepten-2-one <sup>b</sup>	0.16	tr-0.12
53	1339	Hexyl propanoate <sup>b</sup>	0.06	0.17
54	1345	Ethyl <i>trans</i> -2-hexenoate <sup>c</sup>	nd-tr	tr-0.08
55	1347	3-nonanone <sup>b</sup>	0.06	nd-0.12
56	1366	Hexanol <sup>a</sup>	2.87	2.93
57	1374	<i>Trans</i> -3-hexen-1-ol <sup>a</sup>	0.17	0.21
58	1392	<i>Cis</i> -3-hexen-1-ol <sup>a</sup>	0.34	0.79
60	1416	Butyl hexanoate <sup>b</sup>	0.11	0.23
61	1419	Hexyl butanoate <sup>b</sup>	1.10	2.12
63	1439	Ethyl octanoate <sup>a</sup>	0.11	0.08
64	1458	Alpha-cubebene <sup>b</sup>	tr-0.04	tr-0.06
65	1465	<i>Trans</i> -3-hexenylbutanoate <sup>b</sup>	0.12	0.59
66	1476	<i>Cis</i> -3-hexenylbutanoate <sup>b</sup>	0.17	nd-tr
67	1479	Alpha-copaene <sup>b</sup>	tr-0.04	tr-0.07
68	1515	Benzaldehyde <sup>b</sup>	nd	0.23
69	1546	Amyl hexanoate	tr-0.04	tr
70	1559	Beta-linalool <sup>a</sup>	0.58	0.28
71	1570	Octanal <sup>a</sup>	0.06	tr-0.09
73	1614	Hexyl hexanoate <sup>b</sup>	0.54	0.69
74	1661	<i>Cis</i> -3-hexenylhexanoate <sup>b</sup>	0.07	0.21
75	1703	Alpha-terpineol <sup>a</sup>	0.13	tr
76	1709	Benzyl acetate <sup>c</sup>	nd-0.05	nd-0.05
77	1729	Delta-cadinene <sup>b</sup>	nd-tr	tr-0.11
80	1883	Benzyl alcohol <sup>b</sup>	0.07	0.16
82	1978	Dodecanol	0.15	0.19
83	2186	Methyl hexadecanoate <sup>c</sup>	tr-0.04	tr

nd: peak not detected by GC-FID.

tr: trace = peak area <0.04% in chromatogram.

<sup>a</sup> volatile compound identified by mass spectra, retention indices, odor descriptions and volatile standards.

<sup>b</sup> volatile compound identified by mass spectra, retention indices and odor descriptions.

<sup>c</sup> volatile compound identified by mass spectra and retention indices.

<sup>d</sup> IR: retention index of peak in DB-Wax column.

<sup>e</sup> % area: mean of triplicate GC-FID results for volatile compound peak.



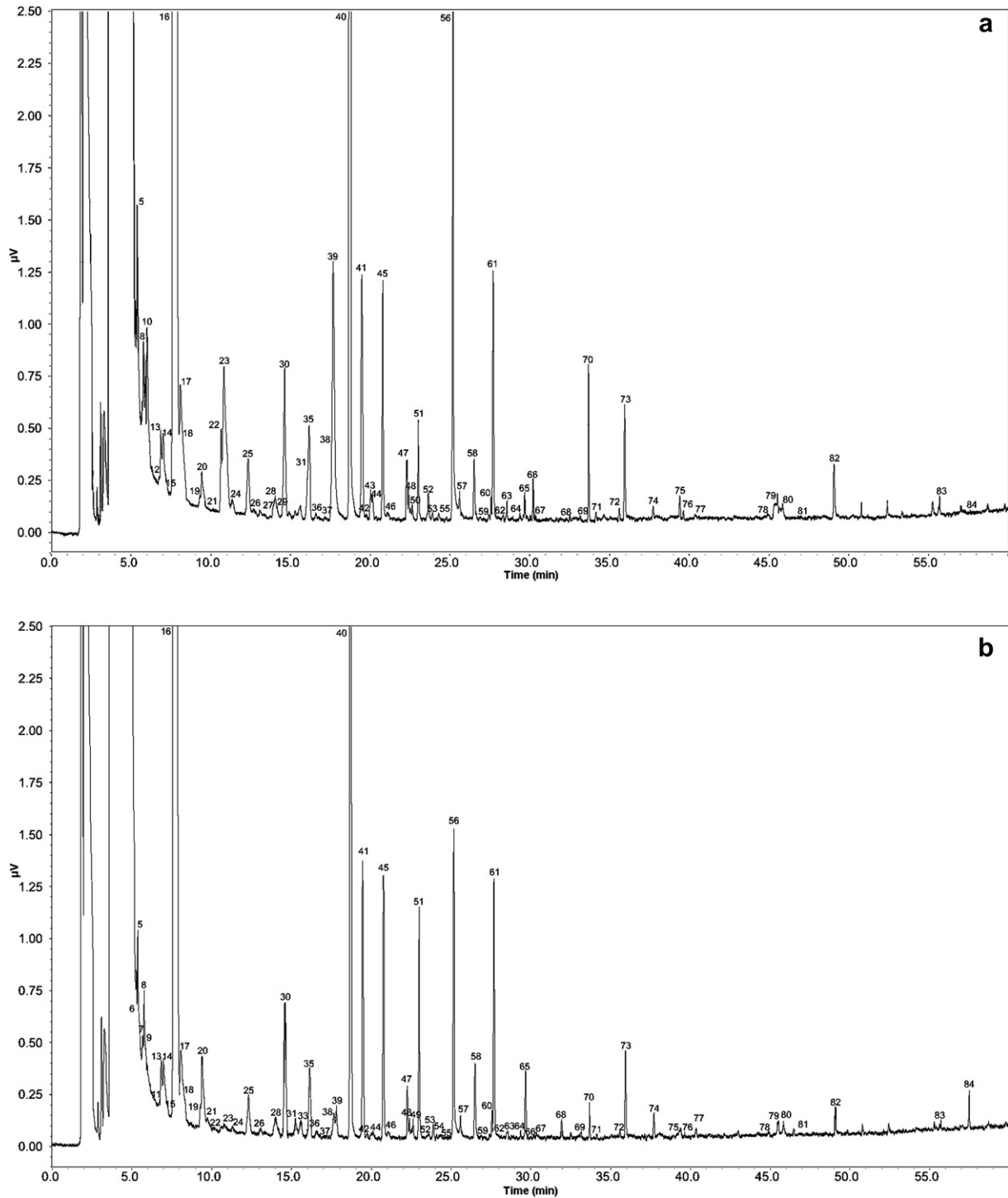


Fig. 1. Gas chromatogram of the organic (a) and conventional (b) Passion fruit pulps.

lemon and sharp) also gave a small odoriferous contribution to both pulps, but it was slightly greater for the conventional passion fruit. Dimethyl disulfide ("passion fruit", sweet, overripe fruit) gave a small contribution to the odor of both organic and conventional fruits (Table 3).

Ethyl butanoate produced the largest area on the chromatogram, as well as one of the highest odoriferous intensities; hexanal (citrus, eucalypt and herbal) showed an aroma of moderate intensity in both organic and conventional fruits, and vinyl benzene

(caramel and rubber) contributed weakly only to the organic fruit aroma. Some important aromas perceived by the judges were not noticed in the chromatograph at the retention time determined by the FID (Figs. 1 and 2). These peaks on the aromagram are identified by letters (Table 3 and Fig. 2). Although undetected by FID, some of these compounds gave an important contribution to both the organic and conventional fruit aroma. These include those that formed peaks I (quince jelly, candy and flowery), L (candy floss and caramel) and O (solvent and plastic).

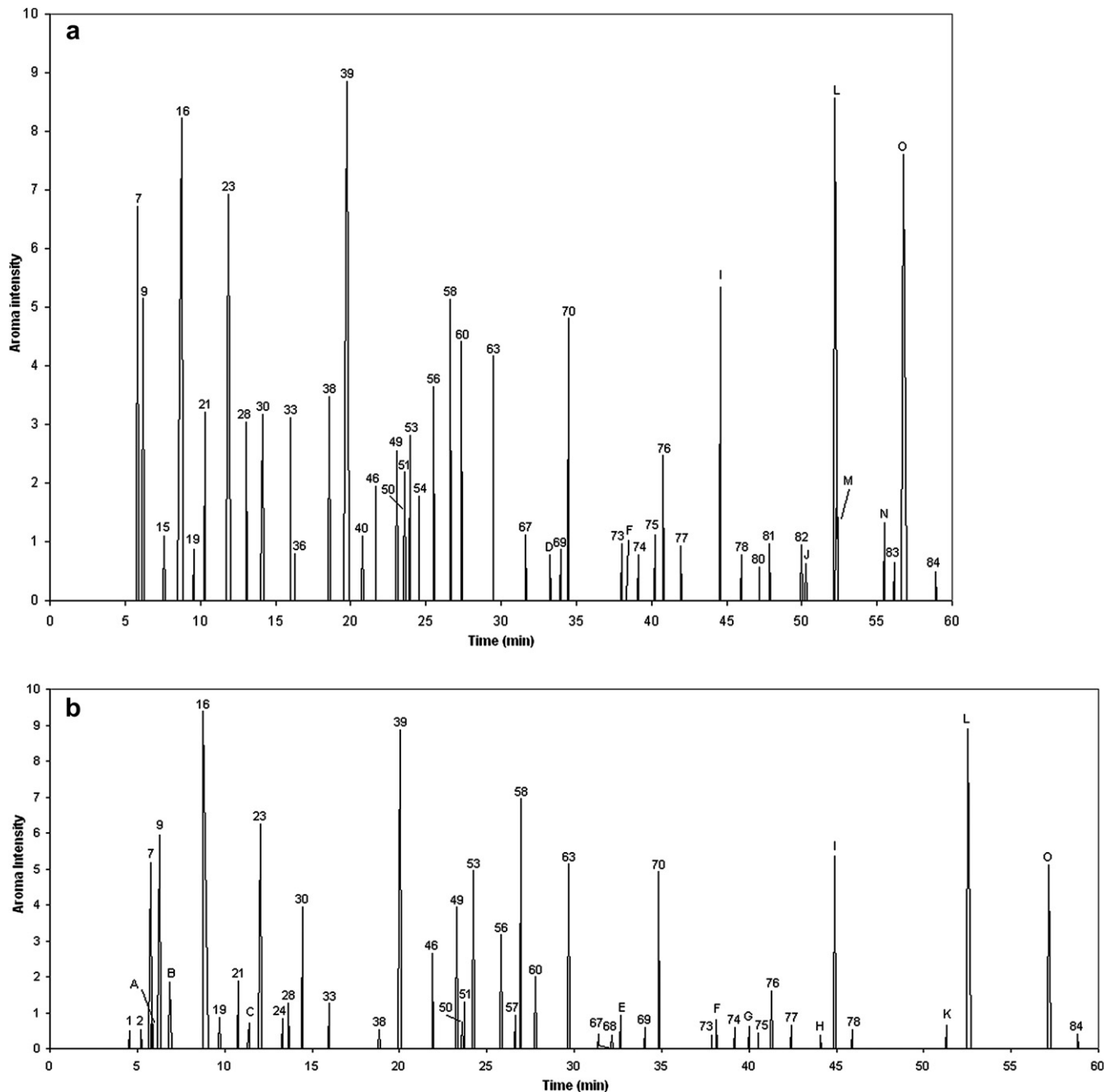


Fig. 2. Consensus aromagram of the organic (a) and conventional (b) Passion fruit pulps.

In other studies using the OSME technique to analyze the odoriferous contributions of the volatile compounds of fruits and beverage (Garruti, Franco, Da Silva, Janzantti, & Alves, 2006; Jales et al., 2005), the judges also reported aroma compounds in regions of the chromatogram in which the FID did not detect any volatile compounds, indicating that the human nose is more sensitive than the FID. The importance of individual volatile compounds in the aroma of passion fruit juice produced in Florida, USA, was analyzed by the olfactometric technique AEDA, using only two judges (Jordán et al., 2002). The compounds found to contribute most to the aroma were 2-methylbutyl hexanoate and 1,3-dimethylbenzene, described as having a nutty and oily, and medicine aroma. These compounds were not detected in our study, perhaps reflecting the different origins of the fruits and the

technique. In a study of conventional passion fruit grown in Fortaleza, CE, in the extreme northeast of Brazil, methyl butanoate, ethyl butanoate, beta-myrcene and ethyl hexanoate were found to be the main contributors to the sweet and fruity aroma, and beta-linalool to the flowery aroma, by means of the OSME technique (Jales et al., 2005). These authors also reported the high intensity of the aroma of diethyl carbonate and 2-pentanone (plastic and glue) and of gamma-terpinolene (metallic).

The differences between the aromas of organic and conventional passion fruit may be attributed largely to the presence of hexanoate and acetate esters and saturated alcohols, which exhibited higher intensities in the organic fruit. Unsaturated alcohols showed higher intensities for the conventional fruit. Besides the above differences, the interaction of plant tissues with abiotic

**Table 3**  
Odor active compounds in organic and conventional passion fruit detected by GC–O–OSME.

Peak	IR <sup>a</sup>	Compound	Description of aroma	Organic	Conventional
				I max <sup>b</sup>	I max <sup>b</sup>
1	<1000	ni	Sour	–	0.49
2	<1000	ni	Passion fruit, peel	–	0.51
7	<1000	Propyl acetate	Passion fruit, sour, flowery	6.72	5.16
A	<1000	2-pentanone	Passion fruit, sulfurous-like, peel	–	1.39
9	<1000	Methyl butanoate	Passion fruit, sweet, strawberry, fruity	5.16	5.93
B	1008	Isobutyl acetate	Sweetish, stink	–	1.86
15	1021	ni	Sharp, peel, woody	1.10	–
16	1033	Ethyl butanoate	Sweet, strawberry	8.23	9.38
19	1069	Dimethyl disulfide	Sweet, passion fruit, overripe fruit	0.87	0.87
21	1077	Hexanal	Sweet, citrus, green	3.22	1.89
C	1098	ni	Rubber, burnt, dry	–	0.72
23	1099	Diethyl carbonate	Synthetic, plastic, metallic	6.93	6.24
24	1109	ni	Sweet, burnt	–	0.82
28	1158	1-butanol	Sharp, flowery, sweet	3.03	1.28
30	1167	Beta-myrcene	Sweet, citrus	3.18	3.93
33	1183	D-limonene	Eucalypt, lemon grass, citrus	3.12	1.27
36	1196	ni	Rubber, flowery	0.79	–
38	1216	<i>Trans</i> -beta-ocimene	Herb, peel, sweet	3.47	0.53
39	1217	Ethyl hexanoate	Sweet, fruity	9.12	8.85
40	1239	Vinyl benzene	Caramel, rubber	1.10	–
46	1282	Octanal	Sweet, fruity, lemon, sharp	1.94	2.64
49	1308	Ethyl <i>cis</i> -3-hexenoate	Leaf, grass, plastic, burnt	2.55	3.93
50	1311	<i>Trans</i> -3-hexenyl acetate	Fruity, citrus	1.33	0.75
51	1319	<i>Cis</i> -3-hexenyl acetate	Citrus, passion fruit, flowery	2.19	1.30
53	1339	Hexyl propanoate	Green banana, strawberry	2.80	4.95
54	1345	Ethyl <i>trans</i> -2-hexenoate	Fruity, burnt, undergrowth	1.77	–
56	1366	Hexanol	Citrus, eucalypt, herbal	3.64	3.17
57	1374	<i>Trans</i> -3-hexen-1-ol	Toasty, stink	–	0.93
58	1392	<i>Cis</i> -3-hexen-1-ol	Sulfur-like, passion fruit, grass	5.12	6.96
60	1416	Butyl hexanoate	Flowery, green	4.42	2.01
63	1439	Ethyl octanoate	Grass, earthy	4.16	5.14
67	1479	Alpha-copaene	Citrus, fruity, passion fruit, sweet	1.11	0.41
68	1515	Benzaldehyde	Citrus, sweet	–	0.36
D	1518	Ethyl 3-hydroxybutanoate	Sweet, toasty	0.78	–
E	1525	Hexyl pentanoate	Peach, earth, undergrowth	–	0.92
69	1546	Amyl hexanoate	Stink, stink bug	0.88	0.59
70	1559	Beta-linalool	Lemon, citrus, sour	4.80	4.92
73	1614	Hexyl hexanoate	Solvent, stink, sulfur-like	0.96	0.36
F	1679	Acetophenone	Sweet, fruity, honey, flowery	1.02	0.79
74	1661	<i>Cis</i> -3-hexenylhexanoate	Passion fruit, undergrowth, sharp	0.77	0.58
G	1680	Germacrene D	Citrus, peppermint, sweet, sharp	–	0.61
75	1703	Alpha-terpineol	Passion fruit, fruity, sharp	1.11	0.44
76	1709	Benzyl acetate	Citrus, flowery, green	2.47	1.60
77	1729	Delta-cadinene	Citrus, flowery	0.93	0.64
H	1780	ni	Flowery, fruity	–	0.38
I	1844	ni	Quince jelly, candy, flowery	5.35	5.37
78	1857	ni	Citrus, sweet, passion fruit leaf	0.77	0.51
80	1883	Benzyl alcohol	Sweet, flowery	0.57	–
81	1916	ni	Flowery, sweet	0.95	–
82	1978	Dodecanol	Sweet, sharp	0.95	–
J	1980	ni	Sharp, leaf, fruity, stink	0.62	–
K	2003	ni	Citrus, caramel, solvent	–	0.66
L	2043	ni	Candy floss, caramel	8.57	8.89
M	2047	ni	Candy floss, caramel	2.10	–
N	2149	ni	Solvent	1.32	–
83	2186	Methyl hexadecanoate	Sharp, solvent	0.64	–
O	2190	ni	Solvent, plastic	7.60	5.10
84	2247	ni	Rubber, toasty	0.49	0.39

A–O letters: compound not detect by GC–FID.

ni: compound not identified by GC–MS.

<sup>a</sup> IR: retention index of peak in DB-Wax column.

<sup>b</sup> I max: maximum intensity of peak in GC–O–OSME, 0 (no odor) to 9 (strong/extreme odor).

and biotic factors, is responsible for physiological changes, particularly the defensive mechanisms induced by pathogens. This leads to the synthesis of protective secondary metabolites, such as terpenes and esters (Gobbo-Neto & Lopes, 2007). In this study, *trans* and *cis*-3-hexenyl acetate and alpha-copaene, alpha-terpineol, D-limonene, *trans*-beta-ocimene and delta-cadinene showed higher aroma intensity for the organic passion fruit, while beta-myrcene and beta-linalool were slightly higher in the conventional fruit

(Table 3). All these compounds provide significant contributions to the characteristic aroma of passion fruit and some, such as the hexenyl acetates, have been described as metabolites that are able to protect the plant (Briskin, 2000; Engelberth, 2006).

Some volatiles not identified, but whose presence was revealed by low peaks on the aromagram of just one of the fruits, may also play a part in the characteristic differences in flavor between the organic and conventional passion fruit (Table 3).

#### 4. Conclusions

The passion fruit volatile composition was not markedly influenced by the cultivation system. The organic and conventional passion fruit showed similar volatile profile, although some differences occurred. Ethyl 2-propenoate, 2-methyl-1-propanol, diethyl carbonate and ethyl hexanoate were threefold higher in the organic fruit while butyl acetate, hexanal, *cis*-3-hexenyl acetate and *trans*-3-hexenyl butanoate were threefold higher in the conventional fruit.

Gas chromatography-mass spectrometry and GC–O allowed the identification of the odoriferous compounds that contributed to the aroma of the passion fruit from both cultivation systems. The hexanoate and acetate esters, and saturated alcohols described as fruity, sweet, citrus and passion-fruit aroma showed the highest odorific intensity in the organic fruit. Furthermore, the *trans* and *cis*-3-hexenyl acetate and the alpha-copaene, alpha-terpineol, D-limonene, *trans*-beta-ocimene and delta-cadinene had higher contribution to the organic passion fruit aroma. On the other hand, the unsaturated alcohols described as grass, sulfur-like and passion-fruit aroma were higher in the conventional fruit. The beta-myrcene and beta-linalool were slightly higher in the conventional passion fruit.

The organic passion fruit showed higher levels of total phenolic compounds and total antioxidant activity than the conventional fruit, suggesting that the cultivation system influenced the production of antioxidant bioactive compounds.

The correlation between instrumental and sensory data enabled the identification of the volatile compounds of greatest importance to the overall aroma of both the organic and conventional passion fruit, and also indicated the differences between the fruits. However, additional research will be needed, especially in order to identify the compounds that provided considerable contributions to the aroma, but which were not detected by the flame-ionization detector.

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