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ORIGINAL PAPER

Characterization of the key aroma compounds in peach by gas chromatography–olfactometry, quantitative measurements and sensory analysis

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Abstract
The volatile compounds of peaches (*Prunus persica* L.) obtained from five cultivars (Chongyanghong, Y1; Ruiguang 19, Y2; Zaohongxia, Y3; Zaohong 2, Y4; and Wuyuehuo, Y5) were analyzed by gas chromatography–olfactometry (GC–O), gas chromatography–mass spectrometry (GC–MS) and GC–flame photometric detection (FPD). A total of 40 odor-active volatile compounds were observed in the GC–O experiments. Amongst those compounds, hexanal, (Z)-3-hexen-1-ol, (E)-2-hexenal, 3-mercaptohexanol, nonanal, γ-nonalactone, and γ-decalactone contributed greatly to aroma of peach. In addition, thirty-four quantified compounds were demonstrated as important odorants according to odor activity values (OAVs > 1). Amongst these compounds, hexanal (OAV: 28–89), pentanal (OAV: 9–16), (E)-2-heptenal (OAV: 19–60), (E)-2-hexenal (OAV: 26–86), (E)-2-octenal (OAV: 10–42), (E)-2-nonenal (OAV: 8–94), γ-decalactone (OAV: 13–34), δ-decalactone (OAV: 2–19), (R)-(−)-linalool (OAV: 29–76) and phenyl acetaldehyde (OAV: 4–59) were the most powerful compounds in five varieties of peach.

Keywords Peaches · Aroma-active compounds · GC–O · OAV

Introduction

The peach (*Prunus persica* L.), is rich in proteases, sugars and other organic compounds in addition to other trace elements and 17 amino acids which are required by human body [1]. The unique aroma of peach is derived from hundreds of volatile compounds that develop during the maturity and ripening stages. These volatile compounds mainly consist of alcohols, esters, lactones, aldehydes, ketones and terpenoids [2–4]. However, not all of the volatile compounds are responsible for the overall aroma of peach. The olfactory impact of these compounds depends on whether their concentrations are greater than their odor perception threshold values, which has led to the use of an odor activity value (OAV) to identify impact odorants [5–7].

Although the majority of aroma volatiles in fruits are esters, aldehydes, and terpenoid hydrocarbons, small quantities of other specific volatile sulfur compounds contribute to the aromas associated with various different foods and often define the characteristic flavor of the food. For example, 1-p-menthene-8-thiol and 4-mercapto-4-methyl-2-pentanone are character impact compounds found in grapefruit [8]. Also, 4-mercapto-4-methyl-2-pentanone, 3-(mercapto) hexyl acetate and 3-mercapto-1-hexanol are important in blackcurrant aroma [9], and methyl ethyl disulfide and diethyl disulfide in the aroma of durian [10]. Sulfur-containing amino acids, such as cysteine, cystine, and methionine, are the major precursors for the formation of the sulfur-containing compounds [11].

Intensive investigations have focused on the evolution of peach and nectarine aromas during the processes of ripening and maturation [4, 12–14]. Several studies have also investigated the effect of culture techniques and management on the composition and content of volatiles. Volatiles may be modified by bagging [15], sun light [16], and post-harvest treatments [17]. Other studies have also investigated the aroma compounds from different cultivars

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[2, 18, 19]. However, an investigation of the key aroma, sulfur compounds and sensory profile in peach has not yet been reported. The aims of the current study were (1) to identify the key aroma compounds in peach samples by GC–O and OAV, (2) to identify volatile sulfurs in peach samples using flame photometric detection (FPD), and (3) to characterize the aroma profile of peach samples by sensory evaluation.

Materials and method

Standard compounds

Acetaldehyde, ethyl acetate, 2-methylbutanal, pentanal, ethyl butanoate, 1-penten-3-one, butyl acetate, hexanal, 3-methylbutyl acetate, β-myrcene, 1-penten-3-ol, limonene, heptanal, 2-pentylfuran, ethyl 2-butenoate, (E)-2-hexenal, *cis*-ocimene, pentanol, hexyl acetate, terpinolene, octanal, *cis*-3-hexenyl acetate, (Z)-2-penten-1-ol, (E)-2-heptenal, 6-methyl-5-hepten-2-one, hexanol, (Z)-3-hexen-1-ol, nonanal, (E,E)-2,4-hexadienal, (E)-2-octenal, 1-octen-3-ol, heptanol, (E,E)-2,4-heptadienal, furfural, 2-ethyl-1-hexanol, decanal, benzaldehyde, (E)-2-nonenal, linalyl acetate, octanol, α-cedrene, β-copaene, (E)-2-decenal, nonanol, phenyl acetaldehyde, acetophenone, α-terpineol, α-citronellol, γ-hexalactone, *cis*-linalool oxide, decanol, geranylacetone, benzyl alcohol, phenylethyl alcohol, β-ionone, γ-nonalactone, γ-decalactone, δ-decalactone, methanethiol, ethanethiol, propanethiol, 2-methylthiophene were purchased from Alfa Aesar Corporation (Tianjin, China). (R)-(−)-Linalool, 3-methylthiophene, thiazole, 2-isopropyl-4-methylthiazole, 4-mercapto-4-methyl-2-pentanone, 3-mercaptohexanol, 8-mercaptomenthone, 3-methyl-2-butene-1-thiol and a homologous series of alkanes (C6-C30) were purchased from Sigma-Aldrich (St. Louis, MO). All of the chemical standards used above were of GC quality.

Materials

The volatile compounds of five peach cultivars (*Prunus persica* L.) were studied: 'Chongyanghong' (Y1, Hebei province), 'Ruiguang 19' (Y2, Beijing), 'Zaohongxia' (Y3, Liao'ning province), 'Zaohong 2' (Y4, He'nan province) and 'Wuyuehuo' (Y5, Shangdong province). The samples were supplied by Shanghai Bairun Flavour & Fragrance Co., Ltd. 1 kg of peaches was crushed and manually deseeded to acquire the peach musts. All musts were kept in a refrigerator (4 °C) until analyzed.

Solid-phase microextraction (SPME)–absorption of aroma compounds

One 75-μm carboxen–polydimethyl siloxane (CAR–PDMS) fiber was preconditioned on gas chromatograph for 30 min before it was used. The injector temperature of gas chromatograph was set at 250 °C. Because the volatile compounds in musts were sensitive to high temperature, the extraction temperature was set at 30 °C. The other optimized SPME experimental conditions were investigated, i.e., 30 min of extraction time and a sample volume of 6 g. The fiber was directly introduced into the GC injector for desorption for 4 min.

Calibration of standard curves

According to our previous research [20], model solution was prepared containing 20 mg/g sucrose, 10 mg/g glucose, 10 mg/g fructose, 3 mg/g citric acid, 1 mg/g (-)-quinic acid in Milli-Q deionized water [21, 22]. A standard stock solution containing 4 mg/kg of methanethiol, 2 mg/kg of ethanethiol, 2 mg/kg of propanethiol, 2 mg/kg of 2-methylthiophene, 2 mg/kg 3-methylthiophene, 2 mg/kg of thiazole, 0.2 mg/kg of 2-isopropyl-4-methylthiazole, 0.02 mg/kg of 4-mercapto-4-methyl-2-pentanone, 1 mg/kg of 3-mercaptohexanol, 0.2 mg/kg of 8-mercaptomenthone and 1 mg/kg of 3-methyl-2-butene-1-thiol in Milli-Q deionized water.

The standard solution was diluted with water according to the proportion of 1:5, 1:10, 1:20, 1:30, 1:40 and 1:50, respectively. 0.01 mL of those diluted solutions containing sulfur compounds and 0.01 mL of the internal standard solution with 0.2 mg/kg of dipropyl disulfide were mixed with model solution. Then the volatile compounds in solution were absorbed by fiber, which was employed in the peach must. The calibration curves were employed to calculate the concentrations of volatile compounds in peach musts. Similarly, 0.01 mL of each of the diluted solutions prepared by other non-sulfur compounds with 0.01 g internal standard solutions containing 5 mg/kg of 2-octanol was introduced into the model solution. Then, the calibration curves for non-sulfur compounds were established. The experiment conducted was repeated thrice.

GC–olfactometry analysis

The GC separation consisted of an Agilent 7890A chromatograph equipped with a flame ionization detector (FID) and an ODP-2 Olfactory Detector Port (Gerstel, Mulheim an der Ruhr, Germany). This system allowed us to simultaneously obtain a FID signal for the quantification and the odor characteristics of each compound detected by sniffing port.

GC effluent was split 1:1 among the FID and sniffing port. Samples were separated on the HP-Innowax analytical fused silica capillary column (60 m × 0.25 mm × 0.25 μm, Agilent, Santa Clara, CA) and HP-5 analytical fused silica capillary column (60 m × 0.25 mm × 0.25 μm, Agilent, Santa Clara, CA). Conditions for GC–O analysis were as follows: the flow rate of carrier gas (hydrogen) was 2 mL/min; the oven temperature was first increased from 40 °C (6 min), ramped at 3 °C/min to 100 °C, and then ramped at 5 °C/min to 230 °C (20 min); the injector and FID detector temperatures were set at 250 and 280 °C, respectively. Moist air was pumped into the sniffing port at 50 mL/min to quickly remove the odorant eluted from the sniffing port. The aroma intensity (AI) was evaluated according to the previous paper [20].

GC–MS identification of aroma compounds

A 7890 gas chromatograph with a 5975C mass selective detector (MSD) (Agilent Technologies, USA) was employed. Two dissimilar columns, HP-Innowax analytical fused silica capillary column (60 m × 0.25 mm × 0.25 μm, Agilent, Santa Clara, CA) and HP-5 analytical fused silica capillary column (60 m × 0.25 mm × 0.25 μm, Agilent, Santa Clara, CA), were used for analyzing the volatile compounds. The injection port was set in a splitless mode for 3 min at 250 °C. The carrier gas was helium that was set at a constant flow rate of 1 ml/min. The MSD was used for chemical identification. Its electron impact energy was 70 eV. The ion source temperature was set at 230 °C. The quadrupole mass filter was operated at 150 °C. The transfer line temperature was at 250 °C. The chromatograms were recorded by monitoring the total ion currents in 30–450 m/z. The oven temperature was held at 40 °C for 6 min, then ramped to 100 °C at the rate of 3 °C/ min and ramped at the rate of 5 °C/min to 230 °C for the last 20 min. The volatile compounds were determined by comparing retention indices, retention times of standard compounds and Wiley7n.l Database (Hewlett–Packard, Palo Alto, CA). The RIs of unknown compounds were determined via sample injection with a homologous series of alkanes (C_6–C_{30}) (Sigma-Aldrich, St. Louis, MO).

Gas chromatography–FPD

The Agilent-7890A GC equipped with a flame photometric detection (FPD) was used in the sulfur mode. Two different phases of columns were employed to separate the volatile compounds. The types of columns were HP-Innowax (60 m × 0.25 mm i.d. × 0.25 μm film thickness, Agilent Technologies, USA) and HP-5 (60 m × 0.25 mm i.d. × 0.25 μm film thickness, Agilent Technologies, USA). The oven temperature was held at 40 °C for 6 min, then ramped to 100 °C at the rate of 3 °C/ min and ramped at the rate of 5 °C/min to 230 °C for the last 20 min. The temperature of FPD detector was set at 250 °C. PMT voltage was set at 500 V. The sulfur compounds were identified with retention times of standard compounds and RIs on both columns. The method of GC–MS analysis was referred for the quantification of sulfur compounds.

Odor activity values (OAV)

The OAV of a compound was calculated by dividing the calculated concentrations with the literature sensory thresholds, which was obtained from the literature.

Sensory analysis

The peaches were evaluated by a well-trained panel of ten members (five males and five females). Before the quantitative descriptive analysis, 10 g peaches was placed in a 100-ml plastic cup covered with Teflon and was subjected to a panelist in laboratory without peculiar smell at 25 °C. Then, the panelists had profoundly discussed aroma compositions of the peaches through three preliminary sessions (each for 2 h), until all of them had agreed with the degree of aromatic flavor. Subsequently, the organoleptic characteristic descriptors were quantified using six sensory descriptors ("alcohol", "fruity", "floral", "green and grassy", "sweet", and "harmony") to evaluate aroma defects and positive features. The complete blocks were estimated for each sample in triplicate for each treatment at random. The mean value of each sample was presented by the triplicate mean score based on ten-point scales.

Statistical analysis

The quantitative descriptive sensory analysis was submitted to analysis of variance (ANOVA). Duncan's multiple comparison tests and Pearson's correlation coefficients were calculated using XLSTAT ver.7.5 (Addinsoft, New York, NY, USA).

Results and discussion

GC–O results for peach samples

By application of GC–O, the aroma compounds detected in the peach samples are summarized in Table 1. The aroma compounds were confirmed in comparison with their RIs, odor characteristics and mass spectra obtained from standard compounds. A total of 40 odor-active volatile compounds were observed in the GC–O experiments. There were four unidentified volatile compounds perceived in five of the peach samples.

Table 1 GC–O identified aroma-active compounds in peach samples with the method of aroma intensity

No.	Compound[A]	RI[B]		Identification basis[C]	Aroma description	Aroma intensity									
		Innowax	HP-5			Y1	SD	Y2	SD	Y3	SD	Y4	SD	Y5	SD
1	Pentanal	936	732	AD, RI, Std	Almond, malt, pungent	2.4ab[D]	0.2	2.2ab	0.3	1.9b	0.2	2.1ab	0.3	3.6a	0.4
2	Hexanal	1078	803	AD, RI, Std	Grass, tallow, fat	2.8c	0.4	3.2b	0.4	2.9c	0.4	3.8ab	0.5	4.5a	0.6
3	(Z)-2-Penten-1-ol	1115	767	AD, RI, Std	Green, plastic, rubber	–[E]	–	1.3	0.1	2.3	0.3	0.7	0.1	1.4	0.2
4	Heptanal	1176	905	AD, RI, Std	Fat, citrus, rancid	1.3b	0.2	1.2b	0.1	1.4b	0.1	2.2a	0.2	2.4a	0.2
5	(E)-2-Hexenal	1194	845	AD, RI, Std	Green, leaf	2.1b	0.3	2.2b	0.2	2.5b	0.2	3.1ab	0.4	3.9a	0.3
6	2-Pentyl furan	1244	934	AD, RI, Std	Green bean, butter	0.6a	0.1	0.7a	0.1	0.5a	0.0	0.8a	0.1	0.9a	0.1
7	Pentanol	1255	766	AD, RI, Std	Balsamic	0.4[F]	0.0	0.5	0.0	–	–	0.6	0.1	0.4	0.0
8	(E,E)-2,4-Hexadienal	1258	910	AD, RI, Std	Green	1.2b	0.1	1.3b	0.2	1.2b	0.1	1.1b	0.1	2.4a	0.3
9	Hexyl acetate	1272	1011	AD, RI, Std	Fruity	1.7b	0.2	1.5b	0.2	1.6b	0.2	1.5b	0.1	2.3a	0.3
10	Heptanol	1273	925	AD, RI, Std	Green	1.1b	0.1	1.2b	0.2	2.4a	0.3	1.3b	0.2	1.2b	0.1
11	Unknown 1	1278	923	AD	Butter	1.5b	0.2	1.7b	0.2	2.1a	0.3	1.8b	0.2	2.6a	0.3
12	Octanal	1284	1009	AD, RI, Std	Fat, lemon, green	1.2b	0.1	1.4b	0.2	2.2ab	0.2	2.3ab	0.2	3.2a	0.3
13	*Cis*-3-hexenyl acetate	1327	1009	AD, RI, Std	Green, leaf	1.2b	0.1	2.3ab	0.2	3.3a	0.3	2.4ab	0.3	2.2ab	0.2
14	(E)-2-Heptenal	1332	962	AD, RI, Std	Soap, fat	1.1c	0.1	1.3c	0.1	2.6b	0.2	2.4b	0.2	3.2a	0.3
15	Hexanol	1360	852	AD, RI, Std	Resin, flower, green	2.3b	0.2	2.4b	0.2	2.2b	0.2	2.5b	0.2	3.5a	0.3
16	4-Mercapto-4-methyl-2-pentanone	1368	953	AD, RI, Std	Sulfur, passion fruit, meat	3.2	0.4	2.5	0.2	2.6	0.2	–	–	–	–
17	Nonanal	1387	1108	AD, RI, Std	Fat, citrus, green	1.1b	0.1	1.3b	0.1	1.2b	0.1	1.2b	0.1	3.6a	0.4
18	(Z)-3-Hexen-1-ol	1391	858	AD, RI, Std	Grass	1.6c	0.1	1.7c	0.2	2.4b	0.3	2.5b	0.2	3.2a	0.4
19	(E,E)-2,4-Heptadienal	1401	1011	AD, RI, Std	Nut, fat	1.2b	0.2	1.3b	0.1	2.7a	0.2	1.2b	0.1	2.5a	0.2
20	(E)-2-Octenal	1409	1055	AD, RI, Std	Green, nut, fat	1.3b	0.1	1.1b	0.1	1.2b	0.2	2.2a	0.3	2.3a	0.3
21	*Cis*-linalool oxide	1420	1070	AD, RI, Std	Flower	0.5b	0.1	0.6b	0.1	0.6b	0.1	1.3a	0.1	1.2a	0.1
22	Furfural	1453	832	AD, RI, Std	Bread, almond, sweet	–	–	0.4	0.0	1.4	0.1	0.5	0.1	0.6	0.0
23	Unknown 2	1462	892	AD	Fruity	1.6	0.1	1.4	0.1	1.5	0.1	–	–	–	–
24	Benzaldehyde	1498	963	AD, RI, Std	Almond, burnt sugar	0.4b	0.0	0.7b	0.1	0.6b	0.1	1.3a	0.1	1.5a	0.1
25	Nonanol	1502	1154	AD, RI, Std	Fat, green	1.3b	0.2	1.1b	0.1	2.5a	0.3	1.2b	0.1	2.7a	0.3
26	(E)-2-Nonenal	1527	1162	AD, RI, Std	Green	0.3c	0.0	0.4c	0.0	1.6b	0.2	2.7a	0.2	2.6a	0.3
27	(R)-(−)-Linalool	1537	1100	AD, RI, Std	Flower, lavender	1.5b	0.1	1.6b	0.2	2.7a	0.3	1.3b	0.1	2.8a	0.3
28	Unknown 3	1576	967	AD	Pungent, malt, green	–	–	1.3	0.2	–	–	1.2	0.1	–	–
29	(E)-2-Decenal	1601	1250	AD, RI, Std	Fat, citrus, green	0.5a	0.0	0.5a	0.0	0.4a	0.0	0.6a	0.1	0.7a	0.1
30	Phenyl acetaldehyde	1625	1049	AD, RI, Std	Hawthorne, honey, sweet	0.4b	0.0	0.5b	0.1	2.2a	0.3	0.6b	0.1	1.9a	0.2
31	Acetophenone	1645	1042	AD, RI, Std	Must, flower, almond	–	–	0.4	0.1	1.3	0.1	0.6	0.1	–	–
32	γ-Hexalactone	1716	998	AD, RI, Std	Sweet, coconut	1.8	0.2	1.7	0.2	–	–	0.9	0.1	–	–
33	Benzyl alcohol	1865	1039	AD, RI, Std	Sweet, flower	0.6a	0.1	0.5a	0.1	0.5a	0.1	0.6a	0.1	0.5a	0.1
34	3-Mercaptohexanol	1876	1125	AD, RI, Std	Sulfur	2.8	0.4	2.9	0.3	–	–	2.3	0.3	–	–

Table 1 (continued)

No.	Compound[A]	RI[B]		Identification basis[C]	Aroma description	Aroma intensity								
		Innowax	HP-5			Y1	SD	Y2	SD	Y3	SD	Y4	SD	Y5	SD
35	8-Mercaptomenthone	1880	1370	AD, RI, Std	Sulfur, passion fruit	1.5	0.2	2.3	0.2	1.2	0.1		0.0	–	–
36	Unknown 4	1906	1379	AD	Smoky, wood	1.2	0.2	1.3	0.1	–	–	1.1	0.1	–	–
37	β-Ionone	1912	1493	AD, RI, Std	Violet, flower, raspberry	1.7	0.2	1.8	0.2	3.7	0.4	1.9	0.2	–	–
38	γ-Nonalactone	2042	1366	AD, RI, Std	Sweet, coconut, peach	2.9a	0.3	2.5b	0.3	2.4b	0.3	2.4b	0.2	2.6b	0.3
39	γ-Decalactone	2103	1472	AD, RI, Std	Sweet, coconut	3.2a	0.3	2.1b	0.2	2.5ab	0.2	2.8a	0.2	2.9a	0.3
40	δ-Decalactone	2208	1469	AD, RI, Std	Sweet, coconut	2.9a	0.2	2.2a	0.2	2.5a	0.2	2.5a	0.3	2.8a	0.3

[A]Volatile compounds detected in the peach samples

[B]Retention index of compounds on HP-5 and Innowax column

[C]Method of identification: *RI* retention index, *Std* confirmed by authentic standards, *AD* aroma descriptor

[D]Values with different superscript roman letters (a–e) in the same row are significantly different according to the Duncan test ($p < 0.05$)

[E]Not perceived

[F]The aroma intensity was evaluated by GC–O

As presented in Table 1, the Y3 sample had the most aroma-active compounds amongst the other peach samples. Of those compounds, hexanal (AI: 2.8–4.5), (Z)-3-hexen-1-ol (AI: 1.6–3.2), (E)-2-hexenal (AI: 2.1–3.9), 3-mercaptohexanol (AI: 2.3–2.9), nonanal (AI: 1.1–3.6), γ-nonalactone (AI: 2.4–2.9), γ-decalactone (AI: 2.1–3.2), δ-decalactone (AI: 2.2–2.9), β-ionone (AI: 1.7–3.7) and 4-mercapto-4-methyl-2-pentanone (AI: 2.5–3.2) were the most powerful aroma-active compounds contributing to the aroma profile of the peach samples, indicating that these compounds are the major contributors of the characteristic aroma which is common to the cultivars investigated. Similar findings also show that C_6 compounds, alcohols, aldehydes and lactones are the major contributors to peach aroma [2]. These C_6 compounds (hexanal, (Z)-3-hexen-1-ol, (E)-2-hexenal) are known products of enzyme-catalyzed breakdown of unsaturated fatty acids. Lactones, particularly γ-decalactone and δ-decalactone, are described as "character impact" compounds in peach aroma, which contributed to the "peachy" background to peach [2].

However, GC–O could not clearly provide information on the potent odorants in the sample as it was measured based on aroma intensity or the odor threshold of the compounds in air. Moreover, loss of the volatile compounds during the isolation and concentration steps was not fully taken into account [23]. Accurate quantification is normally performed to characterize the important aroma compounds through the OAV using the odor threshold of compounds [24, 25].

Quantitative analysis of sulfur volatiles in peach samples

As shown in Table 2, eleven sulfur volatile compounds were detected in this investigation. These were identified based on their retention index in two dissimilar columns compared with standard chemicals and a sulfur-specific FPD response indicates that the detected peaks contained sulfur. On the basis of their chemical structure, these compounds mainly included thiol, thiazole and thiophene. Quantitatively methanethiol, ethanethiol, propanethiol, 3-methylthiophene and 2-methylthiophene showed relatively high amounts compared to other sulfur compounds. It is worth noting that 3-mercaptohexanol (3MH), 8-mercaptomenthone, 2-isopropyl-4-methylthiazole and 4-mercapto-4-methyl-2-pentanone (4MMP) were present in trace amounts in these samples. However, the contribution of each volatile compound to the overall fruit aroma was determined from their aroma intensity and odor activity values. 4-Mercapto-4-methyl-2-pentanone and 3-mercaptohexanol could contribute to the characteristics of passion fruit, broom, black current and citrus, passion fruit, grapefruit, respectively [26]. These were found in peach samples for the first time. According to the previous studies conducted in grapes, 4MMP and 3MH were

Table 2 The concentrations and standard deviation of volatile sulfur compounds in peach samples (μg/kg)

Code	Compound	RI		Identification basis	Concentration (μg/kg)									
		Innowax	HP-5		Y1	SD[A]	Y2	SD	Y3	SD	Y4	SD	Y5	SD
1	Methanethiol	700	500	FPD, RI, Std	0.292ab[B]	0.029	0.475a	0.042	0.442a	0.052	0.456a	0.043	0.194b	0.022
2	Ethanethiol	722	508	FPD, RI, Std	0.342a	0.032	0.133b	0.015	0.243ab	0.026	0.117b	0.013	0.326a	0.041
3	Propanethiol	863	616	FPD, RI, Std	0.352	0.042	0.172	0.018	0.132	0.012	tr	–	tr	–
4	2-Methylthiophene	1107	778	FPD, RI, Std	0.234a	0.027	0.165b	0.017	0.216a	0.027	0.146b	0.016	0.074c	0.009
5	3-Methylthiophene	1120	778	FPD, RI, Std	0.384b	0.036	0.326b	0.038	0.422a	0.05	0.024c	0.002	0.344b	0.041
6	Thiazole	1240	735	FPD, RI, Std	tr[C]	–	0.232	0.022	0.313	0.029	0.172	0.018	0.145	0.013
7	2-Isopropyl-4-methylthiazole	1350	1022	FPD, RI, Std	0.023	0.003	0.033	0.004	0.012	0.001	tr	–	0.007	0.001
8	4-Mercapto-4-methyl-2-pentanone	1368	953	FPD, RI, Std	0.006	0	0.003	0	0.001	0	tr	–	tr	–
9	3-Mercaptohexanol	1875	1127	FPD, RI, Std	0.105	0.01	0.206	0.02	tr	–	0.07	0.005	tr	–
10	8-Mercaptomenthone	1880	1370	FPD, RI, Std	0.006	0	0.014	0.001	0.003	0	tr	–	tr	–
11	3-Methyl-2-butene-1-thiol	1903	964	FPD, RI, Std	tr	–	0.052	0.006	0.082	0.01	0.125	0.011	0.238	0.027

[A]*SD* standard deviation

[B]Values with different superscript roman letters (a–e) in the same row are significantly different according to the Duncan test ($p < 0.05$)

[C]*tr* not detected

released from precursors of which the cysteinylated [S-3-(hexan-1-ol)-L-cysteine (Cys-3MH) and S-4-(4-methylpentan-2-one)-L-cysteine (Cys-4MMP)] and glutathionylated [S-3-(hexan-1-ol)-glutathione (Glut-3MH) and S-4-(4-methylpentan-2-one)-glutathione (Glut-4MMP)] precursors have been identified. From Table 2, the amounts of 4 MMP and 3 MH varied significantly in each of the samples. The different concentrations of these compounds detected between the samples may be attributed to the variety and geographical variations, such as climatic conditions, terrain, water availability and other environmental factors [27, 28]. It is also worth noting that 4MMP and 3MH may contribute greatly to aroma of peach samples due to their extremely low thresholds of 0.8 and 60 ng/kg, respectively [26]. These data agree with that from a previous study which demonstrated these compounds contribute significantly to the aroma profiles of grape wine [9, 26]. 2-Isopropyl-4-methylthiazole, named peach thiazole in the flavor field, is considered a peach and tropical aroma [29]. Concentrations were almost five times as high in the Y2 sample (0.033 μg/kg) compared to the Y5 sample (0.007 μg/kg). It is well known that the concentration of the aroma compounds may not actually reflect the influence on their contribution to the aroma profile in the samples.

Quantitative analysis of volatile compounds

The concentrations and odor activity values (OAVs) of the volatile compounds obtained by GC–MS are displayed in Tables 3 and 4. The major volatile compounds of peach samples were hexanol (2442.54–17991.25 μg/kg), (E)-2-hexenal (2169.55–7077.94 μg/kg), (Z)-3-hexen-1-ol (588.14–1845.51 μg/kg), benzaldehyde (1187.78–10803.38 μg/kg), hexanal (632.04–2005.42 μg/kg). In contrast, (E)-2-octenal (30.39–127.05 μg/kg), (E)-2-nonenal (3.25–37.47 μg/kg), octanal (1.11–25.93 μg/kg) and phenyl acetaldehyde (16.11–236.42 μg/kg) were present at relatively low amounts in each of the samples.

The contributions of compounds to the aroma of samples depended not only on the amounts of the compound but also the odor detection threshold values of compounds. According to the results obtained by Guth, those with OAVs greater than 1 were considered to contribute to the aroma of the samples [30]. Table 4 shows the contributions of the different compounds to the aroma of five samples (OAVs > 1), which indicated that twenty-six, twenty-six, thirty-four, twenty-seven and twenty-nine quantified compounds could be found in the samples at concentrations higher than their corresponding odor thresholds, respectively. These compounds might, therefore, contribute to the peach aroma. Amongst these compounds, ten are the most powerful compounds in five varieties of peach: hexanal (OAV: 28–89), pentanal (OAV: 9–16), (E)-2-heptenal

Table 3 Average values (mean ± standard deviation) (μg/kg) of volatile compounds detected in peach samples

No.	Compounds	Identification basis[A]	RI		Concentration(μg/kg)									
			Innowax	DB-5	Y1	SD	Y2	SD	Y3	SD	Y4	SD	Y5	SD
1	Acetaldehyde	RI, Std, MS	744	< 600	3.89	0.39	tr[C]		6.48	0.78	6.77	0.81	8.84	0.97
2	Ethyl acetate	RI, Std, MS	907	628	124.05d[B]	12.03	96.76e	11.61	635.56a	40.56	297.72c	32.75	535.90b	48.23
3	2-Methylbutanal	RI, Std, MS	912	641	tr		5.85	0.7	12.17	1.58	7.56	0.83	9.53	0.91
4	Pentanal	RI, Std, MS	936	732	525.71c	63.09	473.14d	52.05	681.32bc	95.39	988.34a	94.88	793.56b	95.23
5	1-Penten-3-one	RI, Std, MS	973	680	20.09	2.21	17.48	1.68	24.33	2.36	42.19	5.06	tr	
6	Ethyl butanoate	RI, Std, MS	990	723	5.73d	0.75	6.02d	0.17	10.11b	0.91	12.04a	1.17	8.76c	2.28
7	Butyl acetate	RI, Std, MS	1075	816	261.13b	25.33	219.34b	24.13	465.92a	44.22	490.92a	47.13	404.20ab	80.84
8	Hexanal	RI, Std, MS	1078	803	752.42c	72.23	632.04c	75.84	849.46bc	101.94	1053.43b	136.94	2005.42a	56.15
9	3-Methylbutyl acetate	RI, Std, MS	1102	880	3.76b	0.34	4.51b	0.54	8.66a	1.13	8.27a	0.91	9.10a	1.31
10	(Z)-2-Penten-1-ol	RI, Std, MS	1115	767	tr		101.66	9.86	774.24	100.65	35.88	3.95	113.02	10.85
11	β-Myrcene	RI, Std, MS	1145	992	73.27	8.79	68.88	8.95	103.59	11.39	114.3	13.2	tr	
12	1-Penten-3-ol	RI, Std, MS	1157	686	4.78d	0.62	5.01d	0.14	8.43c	0.76	10.03b	0.97	15.81a	1.9
13	Heptanal	RI, Std, MS	1176	905	13.78	1.34	10.75	1.29	tr		33.08	3.64	59.55	5.36
14	Limonene	RI, Std, MS	1178	1033	25.95b	3.63	18.17b	1.76	20.35b	2.44	48.28ab	5.79	67.35a	7.41
15	(E)-2-Hexenal	RI, Std, MS	1194	845	2332.85c	256.61	2169.55c	195.26	3228.30bc	387.4	5598.85b	671.86	7077.94a	778.57
16	Ethyl 2-butenoate	RI, Std, MS	1215	1002	51.29b	6.15	48.22b	6.27	72.51a	7.98	80.01a	8.24	45.63b	4.87
17	2-Pentyl furan	RI, Std, MS	1244	934	27.92c	3.35	29.32c	0	49.26bc	4.73	59.76b	6.65	95.92a	11.51
18	*Cis*-ocimene	RI, Std, MS	1245	1043	3.58c	0.32	4.29c	0.52	8.25b	1.07	7.87b	0.87	13.12a	1.25
19	Pentanol	RI, Std, MS	1255	766	53.72	6.45	57.48	6.32	tr		322.33	30.94	1450.48	188.56
20	(E,E)-2,4-Hexadienal	RI, Std, MS	1258	910	384.42c	46.13	461.31c	44.75	1107.15b	155	822.67b	98.72	4022.89a	563.2
21	Terpinolene	RI, Std, MS	1266	1082	2.1	0.2	6.31	0.76	30.28	3.33	24.22	3.15	tr	
22	Hexyl acetate	RI, Std, MS	1272	1011	138.32d	15.22	152.16d	14.61	267.80c	25.98	450.95b	54.11	735.05a	95.56
23	Heptanol	RI, Std, MS	1273	925	104.81c	10.17	314.44bc	28.3	1886.65a	207.53	194.95c	23.39	508.83b	48.85
24	Octanal	RI, Std, MS	1284	1009	1.11c	0.13	3.61c	0.47	18.76b	1.8	10.63bc	1.49	25.93a	2.52
25	*Cis*-3-hexenyl acetate	RI, Std, MS	1327	1009	476.42d	61.94	776.57c	108.72	2025.31a	243.04	857.57c	83.18	1157.72b	127.35
26	(E)-2-Heptenal	RI, Std, MS	1332	962	300.15c	29.11	252.12d	27.73	423.57bc	50.83	564.28b	54.17	774.34a	92.92
27	6-Methyl-5-hepten-2-one	RI, Std, MS	1337	984	5.58c	0.61	5.86c	0.56	12.31b	1.35	7.82c	0.94	25.12a	3.26
28	Hexanol	RI, Std, MS	1360	852	3203.57bc	307.54	2242.54d	269.1	3139.52bc	282.56	4997.57b	649.68	17991.25a	1979.04
29	Nonanal	RI, Std, MS	1387	1108	308.85b	40.15	287.23b	34.47	534.26ab	69.45	741.25a	81.54	205.01b	26.65
30	Octanol	RI, Std, MS	1388	981	284.21c	39.79	264.31c	31.72	848.46a	93.33	534.32b	69.46	1090.01a	119.9
31	(Z)-3-Hexen-1-ol	RI, Std, MS	1391	858	588.14	70.58	617.55	80.28	1296.86	155.62	1093.95	131.27	1845.51	177.17
32	1-Octen-3-ol	RI, Std, MS	1394	982	7.46	0.67	tr		18.05	2.17	tr		42.29	4.65
33	(E,E)-2,4-Heptadienal	RI, Std, MS	1401	1011	163.38c	19.61	266.31bc	31.96	868.18a	78.14	349.63b	38.46	985.97a	118.32
34	(E)-2-Octenal	RI, Std, MS	1409	1055	30.39c	3.34	36.47c	4.38	87.53b	8.49	47.41c	5.22	127.05a	12.32

Table 3 (continued)

No.	Compounds	Identification basis[A]	RI		Concentration(μg/kg)									
			Innowax	DB-5	Y1	SD	Y2	SD	Y3	SD	Y4	SD	Y5	SD
35	*Cis*-linalool oxide	RI, Std, MS	1420	1070	3.77d	0.42	4.53d	0.63	19.40c	1.86	43.52b	3.92	77.69a	10.88
36	Furfural	RI, Std, MS	1453	832	tr		16.75	1.84	192.95	23.15	6.98	0.67	21.98	2.86
37	Decanal	RI, Std, MS	1484	1209	22.86c	2.74	21.49c	2.58	45.14c	4.33	148.18b	19.26	466.79a	45.56
38	2-Ethyl-1-hexanol	RI, Std, MS	1487	1032	6.47	0.58	tr		17.13	1.88	38.84	4.66	90.88	10.91
39	Benzaldehyde	RI, Std, MS	1498	963	1187.78c	130.66	1247.17c	162.13	2918.38b	350.21	3872.18b	542.11	10803.38a	1047.93
40	Nonanol	RI, Std, MS	1502	1154	125.18b	15.02	137.70b	12.39	1338.48a	160.62	262.89b	34.18	1340.73a	120.67
41	(E)-2-Nonenal	RI, Std, MS	1527	1162	3.25b	0.31	22.77ab	3.19	7.17b	0.93	37.47a	3.63	29.68ab	3.27
42	(R)-(−)-Linalool	RI, Std, MS	1537	1100	285.85b	37.16	400.45ab	52.06	680.54a	104.81	480.24ab	57.63	759.25a	91.11
43	α-Cedrene	RI, Std, MS	1556	1418	9.36b	0.91	11.23b	1.24	40.45a	3.88	19.66ab	2.36	35.77a	3.22
44	Linalyl acetate	RI, Std, MS	1569	1261	545.42b	65.45	425.43b	41.27	1186.96a	166.17	949.04a	104.4	996.49a	109.61
45	β-Copaene	RI, Std, MS	1591	1430	0.92b	0.1	0.98b	0.12	3.26a	0.39	1.29ab	0.12	2.64a	0.32
46	(E)-2-Decenal	RI, Std, MS	1601	1250	26.61c	2.55	31.93c	3.83	287.43a	37.37	41.51c	4.98	77.63b	8.54
47	Phenyl acetaldehyde	RI, Std, MS	1625	1049	16.11c	2.1	48.34c	5.8	236.42a	26.01	29.97c	4.2	165.11b	19.81
48	Acetophenone	RI, Std, MS	1645	1042	tr		113.09	12.44	203.4	18.31	49.7	4.82	tr	
49	α-Terpineol	RI, Std, MS	1688	1195	tr		17.88	1.72	75.12	9.01	tr		tr	
50	γ-Hexalactone	RI, Std, MS	1716	998	1420.57	170.47	832.11	108.17	tr		634	69.74		
51	α-Citronellol	RI, Std, MS	1762	1233	12.35d	1.11	58.80c	7.06	218.75a	24.06	80.05bc	9.61	114.31b	13.72
52	Decanol	RI, Std, MS	1765	1263	80.02c	10.4	85.60c	8.3	410.91b	49.31	761.66a	91.4	906.38a	87.92
53	Geranylacetone	RI, Std, MS	1840	1448	17.74	2.48	53.23	6.39	tr		29.81	3.28	47.13	5.18
54	Benzyl alcohol	RI, Std, MS	1865	1039	7.62c	0.74	24.69b	2.4	161.03a	22.54	14.33c	1.38	29.23b	2.81
55	β-Ionone	RI, Std, MS	1912	1493	221.23	21.24	705.93	67.77	1206.5	132.72	331.72	43.12	tr	
56	Phenylethyl alcohol	RI, Std, MS	1925	1118	0.39	0.04	tr		14.81	1.44	0.83	0.1	1.51	0.18
57	γ-Nonalactone	RI, Std, MS	2042	1366	629.16a	75.5	538.88a	64.67	216.64b	40	45.51c	6.37	250.71b	30.08
58	γ-Decalactone	RI, Std, MS	2103	1472	1616.56a	210.15	1409.31a	560	600.68b	1440.86	594.86b	57.7	806.98b	166.63
59	δ-Decalactone	RI, Std, MS	2208	1469	1904.48a	228.54	1256.08b	44.23	1368.46b	177.84	194.34c	21.38	1843.03a	228.36

[A]Method of identification: *MS* mass spectrum comparison using Wiley library, *RI* retention index in agreement with the literature value, *Std* confirmed by authentic standards

[B]Values with different superscript roman letters (a–e) in the same row are significantly different according to the Duncan test ($p < 0.05$)

[C]Not detected in sample

Table 4 The OAVs of volatile compounds detected in peach samples

No.	Compounds	OAV					Thresholds (μg/kg)	References
		Y1	Y2	Y3	Y4	Y5		
1	Acetaldehyde	< 1	< 1	< 1	< 1	< 1	10	C
2	Ethyl acetate	< 1	< 1	< 1	< 1	< 1	6200	C
3	2-Methylbutanal	–[A]	6	12	8	10	1	C
4	Pentanal	9	8	11	16	13	60	C
5	1-Penten-3-one	< 1	< 1	1	2	–	23	C
6	Ethyl butanoate	6	6	10	12	9	1	D
7	Butyl acetate	5	4	8	8	7	58	C
8	Hexanal	33	28	38	47	89	22.5	C
9	3-Methylbutyl acetate	2	2	4	4	5	2	C
10	(Z)-2-Penten-1-ol	–	< 1	1	< 1	< 1	720	D
11	β-Myrcene	< 1	< 1	1	1	–	100	D
12	1-Penten-3-ol	< 1	< 1	< 1	< 1	< 1	400	C
13	Heptanal	< 1	< 1	< 1	< 1	< 1	550	C
14	Limonene	< 1	< 1	1	1	< 1	200	D
15	(E)-2-Hexenal	28	26	39	68	86	82	C
16	Ethyl 2-butenoate	–	–	–	–	–	NF[B]	
17	2-Pentyl furan	5	5	8	10	16	5.9	C
18	*Cis*-ocimene	< 1	< 1	< 1	< 1	< 1	34	D
19	Pentanol	< 1	< 1	< 1	< 1	< 1	5000	C
20	(E,E)-2,4-Hexadienal	6	8	18	14	67	60	D
21	Terpinolene	< 1	< 1	< 1	< 1	< 1	41	D
22	Hexyl acetate	1	1	2	4	6	115	D
23	Heptanol	< 1	< 1	5	< 1	1	400	D
24	Octanal	2	5	27	15	37	0.7	C
25	*Cis*-3-hexenyl acetate	–	–	–	–	–	NF	
26	(E)-2-Heptenal	23	19	33	43	60	13	C
27	6-Methyl-5-hepten-2-one	< 1	< 1	< 1	< 1	< 1	50	C
28	Hexanol	6	4	6	10	36	500	C
29	Nonanal	8	7	13	19	5	40	C
30	Octanol	3	2	8	5	10	110	C
31	(Z)-3-Hexen-1-ol	8	9	19	16	26	70	C
32	1-Octen-3-ol	5	–	12	–	28	1.5	C
33	(E,E)-2,4-Heptadienal	3	5	16	6	18	56	C
34	(E)-2-Octenal	10	12	29	16	42	3	C
35	*Cis*-linalool oxide	< 1	< 1	< 1	< 1	< 1	100	D
36	Furfural	< 1	< 1	< 1	< 1	< 1	282	C
37	Decanal	< 1	< 1	2	5	16	30	D
38	2-Ethyl-1-hexanol	< 1	< 1	< 1	< 1	< 1	1280	C
39	Benzaldehyde	4	4	9	12	34	320	D
40	Nonanol	< 1	< 1	1	< 1	1	1000	D
41	(E)-2-Nonenal	8	57	18	94	74	0.4	D
42	(R)-(−)-Linalool	29	40	68	48	76	10	C
43	α-Cedrene	–	–	–	–	–	NF	
44	Linalyl acetate	< 1	< 1	1	< 1	1	1000	D
45	β-Copaene	–	–	–	–	–	NF	
46	(E)-2-Decenal	2	2	17	2	5	17	D
47	Phenyl acetaldehyde	4	12	59	7	41	4	C
48	Acetophenone	–	2	3	< 1	–	65	D
49	α-Terpineol	–	–	< 1	–	–	5000	D

Table 4 (continued)

No.	Compounds	OAV					Thresholds (μg/kg)	References
		Y1	Y2	Y3	Y4	Y5		
50	γ-Hexalactone	28	17	–	13	–	50	D
51	α-Citronellol	< 1	< 1	< 1	< 1	< 1	400	D
52	Decanol	< 1	< 1	< 1	1	1	700	D
53	Geranylacetone	< 1	< 1	< 1	< 1	< 1	186	D
54	Benzyl alcohol	< 1	< 1	2	< 1	< 1	100	C
55	β-Ionone	32	101	172	47	–	7	C
56	Phenylethyl alcohol	< 1	< 1	< 1	< 1	< 1	60	C
57	γ-Nonalactone	25	22	9	2	10	25	D
58	γ-Decalactone	34	30	13	13	17	47	D
59	δ-Decalactone	19	13	14	2	18	100	D

[A]The OAV was not calculated in sample

[B]The detection threshold was not found in reference

[C]Zhu J, Chen F, Wang L, Niu Y, Yu D, Shu C, Chen H, Wang H, Xiao Z (2015) Comparison of aroma-active volatiles in oolong tea infusions using GC–olfactometry, GC–FPD, and GC–MS. J Agric Food Chem 63(34):7499–7510

[D]Van Gemert LJ (2003) Compilations of odour threshold values in air, water and other media. Van Setten Kwadraat, Houten

(OAV: 19–60), (E)-2-hexenal (OAV: 26–86), (E)-2-octenal (OAV: 10–42), (E)-2-nonenal (OAV: 8–94), γ-decalactone (OAV: 13–34), δ-decalactone (OAV: 2–19), (R)-(−)-linalool (OAV: 29–76) and phenyl acetaldehyde (OAV: 4–59). Interestingly, they were mainly aldehyde compounds. These results were consistent with the findings that the odor threshold values of aldehyde compounds are generally lower than the concentrations of these compounds [20].

For the Y5 sample, the OAVs of the hexanal, (E)-2-heptenal, (E)-2-hexenal and (E)-2-octenal from the Shangdong region are significantly higher than the other regional peaches. These compounds can exert a strong influence on peach aroma. Concerning theY4 sample, the OAVs of pentanal and (E)-2-octenal from the Henan region are the highest amongst the five regional peaches. These compounds are responsible for the green, fresh, citrusy, and fatty notes. The results are consistent with previous investigations which show aldehydes with six to ten carbons are perceived as having green, fatty, or tallow aromas [20]. Although most aldehydes can contribute to special and characteristic green, fatty, or tallow aromas at low levels, they also lead to rancid, painty or other unpleasant favors when present at high levels due to their low threshold. For example, hexanal has a low detectable odor threshold of 4.5 μg/kg [31]. At low concentrations, it contributes to the desirable green, fresh and fatty notes of aroma but presents "oxidized" off-flavors when concentrations accumulate above a critical level. The content of most aldehydes should be controlled within a suitable range which was further confirmed by the findings of sensory evaluation [31].

Two important terpenoid compounds, β-ionone and (R)-(−)-linalool, were detected in the study. (R)-(−)-Linalool, with lilac, lavender sensory properties, has a low threshold value of 10 μg/kg. The highest OAV of this volatile was obtained in sample Y5 (76), and lowest one in sample Y1 (29). β-Ionone, which may be considered a floral aroma, exhibited the highest OAV (172) in Y3 and was absent in the Y5 sample. These compounds could significantly contribute to the overall aroma of the peach samples and agree with the analysis of GC–O in the study.

Lactone compounds such as γ-hexalactone, γ-nonalactone, γ-decalactone and *δ*-decalactone were also identified in this study, which were compounds that contributed to the characteristic fruity and sweet odors of the peach samples. As summarized in Table 3, sample Y1 exhibited higher amounts of these compounds and OAVs than those in other peach samples. Based on the OAV, the most powerful aroma-active lactone compound was γ-hexalactone in sample Y1. This compound was considered as the key odorant in sample Y1. According to previous investigations, lactones have been reported as character impact compounds in peach aroma which contributed to the background of peaches. The study also presented flavors specific to peach aroma that are associated with C_6 aldehydes, C_6 alcohols and terpenoids [4, 19].

Sensory analysis

Sensory analysis was performed by evaluating the organoleptic quality of five kinds of peach samples using six descriptors that included "alcohol", "fruity", "floral",

"green" and "grassy", "sweet" and "harmony". ANOVA was employed to distinguish statistical differences between peach samples through sensory evaluation scores (data not shown). The statistical analysis demonstrated that samples showed dramatic differences in each of the descriptors ($p < 0.05$) (Fig. 1). These noticeable differences suggested each of the samples had significantly different flavor intensities. The panelists were also a significant influencing factor on all descriptors. This phenomenon was not unusual in characteristic descriptive analysis and indicated that panelists applied different levels of qualitative scoring because of physiological diversities in the perceived intensity or differences in personal preference, such as central or extreme raters [20].

Y1 and Y5 samples were accompanied by "alcohol", "green" and "grassy" descriptors more frequently than the other samples. The major compounds involved in these descriptors include hexanol, (Z)-3-hexen-1-ol, hexanal, pentanal, (E)-2-heptenal, (E)-2-hexenal, (E)-2-octenal and (E)-2-nonenal, as described by panelists of GC–O. The result was in agreement with previous investigations that showed aldehydes and alcohols are generally associated with "green", "fresh grass", "green plants" and "citrusy notes". Y3 sample was rated with the highest value of the fruity descriptor, whilst Y1 indicated the lowest sensorial score. It is common knowledge that the "fruity" descriptor is the predominant and most fundamental part of the global flavor of peach. Therefore, this descriptor was an important symbol in measuring the quality of peach aroma. According to previous studies, the "fruity" descriptor was mainly associated with ester compounds [20]. In this study, ethyl butanoate, butyl acetate, 3-methylbutyl acetate and hexyl acetate presented relatively high OAVs in the samples.

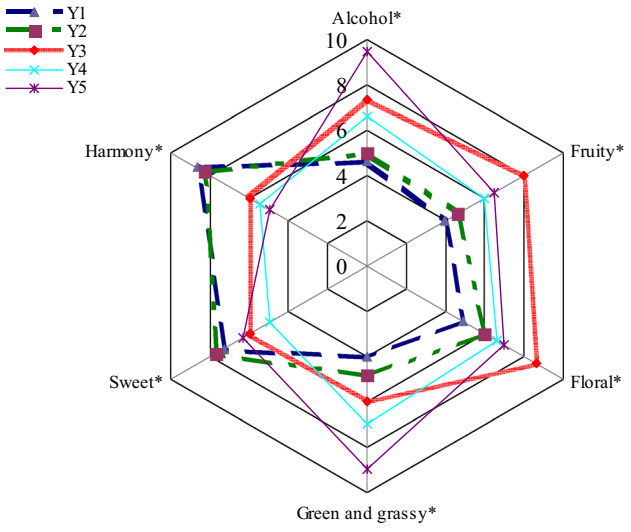

Fig. 1 Aroma profiles of peach samples obtained from Y1, Y2, Y3, Y4 and Y5 samples. In sensorial parameters indicated with an (*) a difference among some trials is verified for $p < 0.05$

These compounds might contribute to the "fruity" descriptor. "Floral" was also an important aroma descriptor which had its highest aroma score in sample Y3 and the lowest score in sample Y1. It was mainly composed of terpenoids, such as β-ionone and (R)-(−)-linalool. The Y2 sample was accompanied by the "sweet" descriptor more than any of the other samples. This phenomenon indicated that the Y2 sample yielded the highest amount of compounds and was able to influence a "sweet" aroma in its corresponding peach. The major aroma-active compounds in the "sweet" category mainly included lactones, such as γ-hexalactone, γ-nonalactone, γ-decalactone and δ-decalactone, as described by panelists of GC–O. The highest score under the "harmony" descriptor was found in the Y1 sample, whereas the lowest score was found in sample Y5. Notably, by comparing the sensory analysis of the "harmony" and "green and grassy" descriptors, these two descriptors showed the complete opposite when scored by the judges. Undoubtedly, aldehyde compounds played important roles in the overall aroma of peaches. It is also noted that these compounds were positively correlated with the aroma quality of the samples in suitable amounts. Otherwise, these compounds were perceived as offensive and conferred a negative sensory contribution to the aroma of samples [31].

Correlations between sensory descriptors and volatile compounds

An overview of the Pearson correlation analysis conducted between the sensory descriptors and the volatile compounds is shown in Table 5 (shown in the Supporting material). Strong positive correlations were observed in our study between "alcohol" and "green and grassy" ($r = 0.945$), and between "fruity" and "floral" ($r = 0.980$). Moderately positive correlations were observed between "floral" and "green and grassy" ($r = 0.498$), "fruity" and "green and grassy" ($r = 0.590$). A significantly strong relationship between "alcohol" and "green and grassy" may be explained by the fact that most of the volatile compounds were common in those two descriptors, such as hexanol, (Z)-3-hexen-1-ol, hexanal, pentanal, (E)-2-heptenal, (E)-2-hexenal, (E)-2-octenal and (E)-2-nonenal. The strong negative correlations were reported in this study between "alcohol" and "harmony" ($r = -0.904$), "green and grassy" and "harmony" ($r = -0.926$), whilst the "sweet" descriptor showed a moderate negative correlation with "alcohol" ($r = -0.497$) and with "green and grassy" ($r = -0.576$).

Regarding the volatile compounds, the groups of high correlation were found. From Table 5, a large number of saturated and unsaturated C_5, C_6 and C_7 aldehydes and alcohols were strongly correlated with each other. For example, strong correlations were also observed between hexanal and (E)-2-hexenal ($r = 0.914$), (E)-2-heptenal ($r = 0.946$), hexanol ($r = 0.990$), and

(Z)-3-hexen-1-ol ($r=0.893$); between (E)-2-hexenal and (E)-2-heptenal ($r=0.986$), (E)-2-octenal ($r=0.872$), (E)-2-nonenal ($r=0.816$); between (Z)-3-hexen-1-ol and (E)-2-hexenal ($r=0.858$), octanal ($r=0.986$), (E)-2-heptenal ($r=0.924$), and octanol ($r=0.983$).

Otherwise, the strong negative correlations also were observed in this study between γ-hexalactone and 2-methylbutanal ($r=-0.964$), octanal ($r=-0.936$), (Z)-3-hexen-1-ol ($r=-0.876$), (E)-2-octenal ($r=-0.878$), (E,E)-2,4-heptadienal ($r=-0.940$), (R)-(−)-linalool ($r=-0.978$), and octanol ($r=-0.903$). Interestingly, similar phenomenon was observed between γ-decalactone and 2-methylbutanal ($r=-0.876$), pentanal ($r=-0.824$), octanal ($r=-0.757$), (Z)-3-hexen-1-ol ($r=-0.737$), nonanal ($r=-0.615$), (E)-2-octenal ($r=-0.602$). This result demonstrated that lactone compounds presented a negative correlation with aldehydes and alcohol compounds which was partly the result of the negative relationship between "sweet" and "alcohol" and "green and grassy".

Conclusions

The volatile compounds of peaches obtained from five cultivars were analyzed by GC–MS, GC–O, GC–PFD and OAV. Of these compounds, hexanal, (Z)-3-hexen-1-ol, (E)-2-hexenal, 3-mercaptohexanol, nonanal, γ-nonalactone, γ-decalactone, δ-decalactone, β-ionone, (R)-(−)-linalool, phenyl acetaldehyde and 4-mercapto-4-methyl-2-pentanone were the most powerful aroma-active compounds contributing to the aroma profile of the peach samples. The data presented in this study lay a foundation for the establishment of a chromatographic library of characteristic aroma compounds from different varieties of peach and can be used to evaluate peach quality. Furthermore, it provides the basis for the identification of varieties and quality control based on characteristic aroma compounds.

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Compliance with ethical standards

Conflict of interest The authors have declared no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subjects.

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