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A comparative analysis of the volatile components of green tea produced from various tea cultivars in China

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Abstract: China is a major producer and consumer of green tea and possesses numerous high-quality tea cultivars, which can be used to make green tea. However, the green teas produced from these tea cultivars vary markedly in aroma. In this study, a sensory evaluation method and headspace solid-phase microextraction combined with GC-MS were employed to determine the primary substances that contribute to the aromas and key differences in the aroma components of green tea produced from 20 tea cultivars. The results revealed 57 major volatile components, among which aldehydes, alcohols, and esters were the most prevalent. For the volatile components, the linalool, nonanal, and geraniol contents were the highest, followed by dimethyl sulfide, methyl salicylate, heptanal, and caproicacidhexneylester. The volatile components varied considerably among the green tea samples, and some contained substances with a high content that gave off unique aromas. The correlation analysis revealed significant correlations between the sensory evaluation scores and contents of linalool, geraniol, methyl salicylate, cis-linalool oxide, 3-carene, phenethyl alcohol, limonene, (Z)-3-cis-3-hexenyl isovalerate, citral, (E)-β-ocimene, alcohols, esters, and alkenes, as well as between the sensory evaluation scores and total volatile component contents. Aromatic substances with the highest odor activity values were, in descending order, linalool, capraldehyde, dimethyl sulfide, β-ionone, geraniol, nonanal, heptanal, (E)-2-nonenal, and caproicacidhexneylester. These substances were the major contributors to aroma formation in the green tea samples. The principal component analysis and orthogonal projections to the latent structure-discriminant analysis suggested that the 20 tea cultivars could be grouped into 6 categories and that the high content of linalool, nonanal, and geraniol substantially contributed to the categorization of the tea cultivars. A key variable analysis revealed that 23 volatile components played a critical role in the categorization of the tea cultivars.

Key words: Tea cultivars, green tea, volatile components, odor activity value, principal component analysis

1. Introduction

Camellia sinensis (L.) Kuntze is a perennial woody tea plant that is widely cultivated for the production of a popular nonalcoholic beverage (Wei et al., 2018). Tea plants originated in southwestern China, have been grown for more than 2 millennia, and exhibit a wide range of tea germplasm resources (Chen and Zhou, 2005; Chen et al., 2012). Due to the large genetic variation among tea germplasm resources, teas produced from these germplasm resources vary considerably in characteristics such as color, flavor, and aroma (Li et al., 2016). The volatile substances (in varying concentration combinations) in tea produce aromas that are sensed by human olfactory nerves. Although these substances generally account for only 0.01%–0.05% of tea, they are crucial indicators of tea quality (Baba and Kumazawa, 2014; Baldermann et al., 2014). Tea aromas can be grouped into 4 categories according to the aroma formation pathways, which comprise those with carotenoids as precursors, lipids as precursors, glycosides as precursors, and products from Maillard reactions (Yang et al., 2013; Ho et al., 2015). Tea aromas vary based on the different precursor material contents, component ratios, and glycoside hydrolase properties of the corresponding tea cultivars. Accordingly, various tea cultivars produce various types of tea aromas, each of which is unique to each corresponding tea cultivar (Zhang et al., 2006; Wang et al., 2015; Wang et al., 2016).

Tea cultivars are the foundation of the tea industry and determine the yield, quality, and economic viability of tea (Chen et al., 2007). In the world's major tea-producing countries, breeding a variety of tea cultivars is considered crucial to tea production. China is a major producer and consumer of green tea, and numerous high-quality tea cultivars that can be used to produce green tea are cultivated domestically (Graham, 1992; Ma et al., 2015). Internal and external factors cause variations in

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the aroma components of the green tea produced from these tea cultivars. Some of the green teas produced from the tea cultivars emit a pleasant chestnut flavor, whereas others emit a pleasant floral or fruity flavor (Cho et al., 2007; Han et al., 2016). However, few systematic studies of green tea from a variety of tea cultivars have investigated the volatile components that contribute to tea aroma and cause key aroma differences. Therefore, 20 tea cultivars, encompassing varieties from most green tea production regions in China, were selected for evaluation in this study. Many methods were used to analyze and compare the green tea aroma characteristics and volatile components to determine the main substances responsible for the aromas and substances that contributed to key aroma differences, such as sensory evaluation, headspace solid-phase microextraction combined with gas chromatography-mass spectrometry (HS-SPME-GC-MS), odor active value (OAV), principal component analysis (PCA), and orthogonal projections to latent structure-discriminant analysis (OPLS-DA). The aims of our investigation were to provide producers with a clearer understanding of the outstanding characteristics and production performance of these tea cultivars, promote the cultivation of high-quality tea cultivars, and provide a theoretical basis for research on breeding tea cultivars with unique aromas.

2. Materials and methods

2.1. Experimental materials

The samples used in the experiment were obtained from the tea garden of the Fruit and Tea Research Institute of the Hubei Academy of Agricultural Sciences (30.29518°N, 114.14673°E). In 2013, the 1-year-old cutting seedlings (all identical in size) of 20 tea cultivars (Supplementary Table 1) were planted in an experimental field surrounded by an open space with flat terrain, favorable soil structure, and moderately fertile soil. The area of the experimental field was 13.5 m^2 and 3 independent replicates for each tea cultivar were planted in a random order. The planting methods were as follows: large rows were 150 cm apart, small rows were 40 cm apart, the plant spacing was 20 cm apart, and cutting seedlings pairs were planted in parallel rows using the pit method. The same cultivation and management measures were adopted for all of the cutting seedlings. In March 2017, the shoots (1 bud and 2 leaves) were harvested and then spread out in an air-conditioned room (temperature: 18–20 °C, relative humidity: 75%) until the water content was 60%–65%. Afterwards, the samples (100–250 g) were put into a rotary continuous fixation machine at 150–180 °C for 5–7 min, to terminate the endogenous enzymatic reaction, until the grass taste disappeared and tea aroma appeared. The samples were then put into a rolling machine for 8–10 min until the right shape and a lot of liquid appeared. Subsequently, the tea samples were parched in a tea dryer at 120–125 °C for 10–15 min, and then spread out to cool. Finally, the tea samples were redried in a tea dryer at 70–75 °C for 8–10 min until the water content was 5%–6%, and then the samples (Figure 1) were stored in a freezer at –20 °C for further use.

2.2. Reagents and apparatus

Ethyl decanoate with a purity of 99% (Sigma-Aldrich, USA) was used in the experiment. The apparatuses used in this study were as follows: a manual SPME injector and 50/30-μm divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) SPME head (Supelco, USA), a 7890A gas chromatograph and 5975C mass spectrometer (Agilent, USA), an HHS-type thermostat water bath (Shanghai Boxun Industry & Commerce Co., Ltd., China), and a Milli-RO PLUS 30 water purifier (Millipore, France).

2.3. Experiment methods

2.3.1. Aroma score of sensory evaluation

All of the tea samples were evaluated by 5 professional tea tasters from the Tea Research Institute, Chinese Academy of Agricultural Sciences, in accordance with the GB/T 23776-2009 method for evaluating high-quality green tea. In brief, the samples were blind-coded with random numbers. Next, 3 g of the samples was infused with 150 mL of boiled purified water in separated white porcelain cups and maintained for 5 min. Following that, the tea was tasted by the tea tasters, who assigned scores for the aroma between 1 and 100, with 1 being bad or extremely disliked and 100 being good or extremely liked.

2.3.2. HS-SPME method

Next, 3 g of a tea sample was precisely weighed and placed into an extraction bottle. Subsequently, 150.0 mL of boiling water was added, followed by 2.00 μL of internal standard substance (12 mg L^{-1} ethyl decanoate). A SPME handset equipped with a 50/30-μm DVB/CAR/PDM extraction head (the extraction head was aged for 15 min at 250 °C prior to the experiment) was then inserted into the extraction bottle through the rubber bottle cap, and the handset was placed in a 50 °C water bath for 10 min. After the extraction head had adsorbed for 50 min, it was removed and immediately inserted into the inlet of the GC apparatus to desorb for 3 min. The apparatus was then used to collect data. All of the green tea sample extractions were performed in 3 independent replicates.

2.3.3. GC-MS analysis

The conditions and apparatus used in the GC were an HB-5MS (30 m × 0.32 mm × 0.25 μm) elastic quartz capillary column (Agilent Technologies, Santa Clara, CA, USA), an inlet temperature of 240 °C, high purity helium (as the carrier gas), and a flow velocity of 1.0 mL/min.

The column heating procedure was as follows. The column was maintained at 50 °C for 5 min. Subsequently,

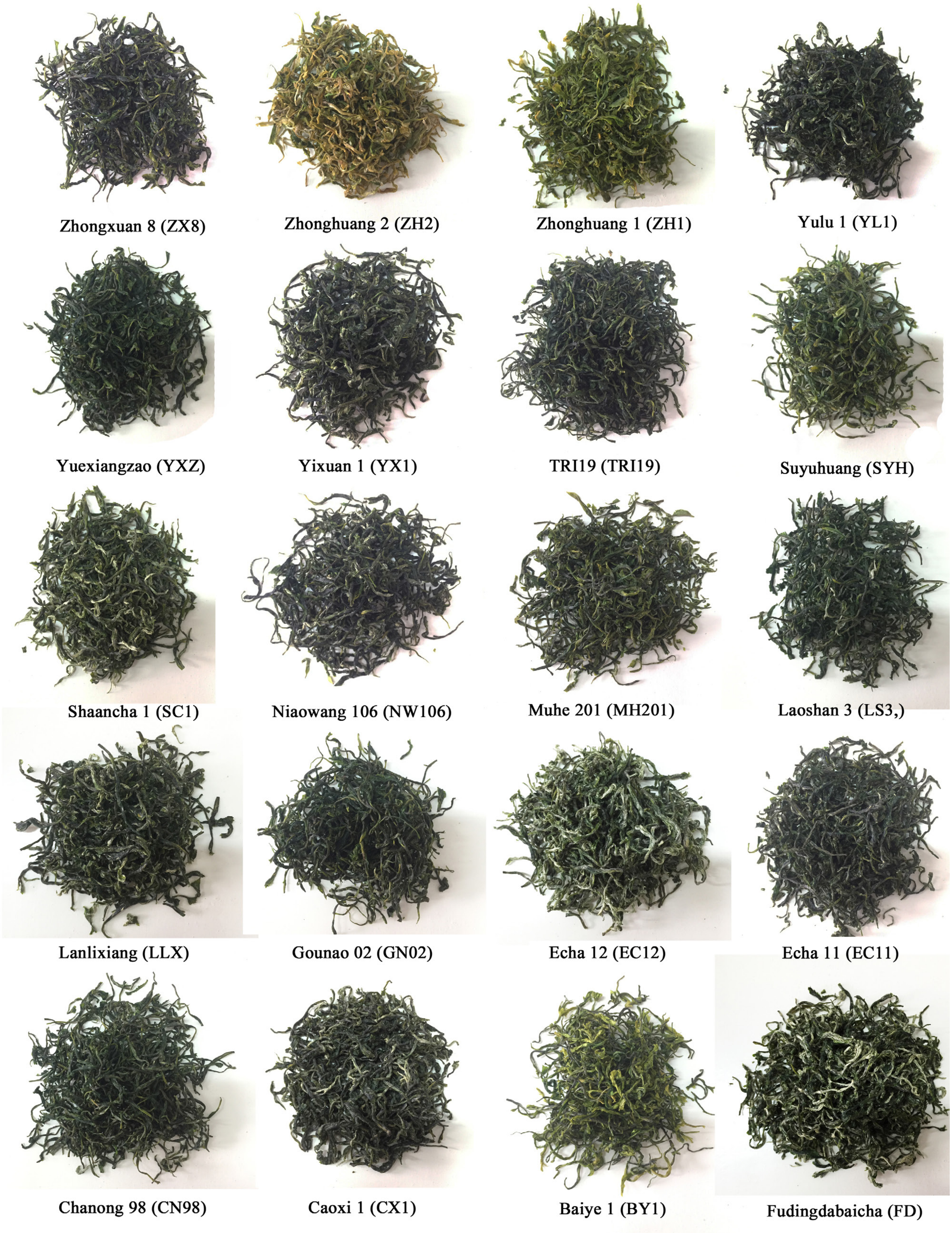

Figure 1. Information about the green tea produced from the various tea cultivars.

the temperature was increased 3 °C/min until it reached 180 °C. The column was maintained at this temperature for 2 min, after which the temperature was increased 10 °C/min until it reached 250 °C. Finally, the column was maintained at this temperature for 3 min.

Conditions set for the MS were as follows: an ionization energy of 70 eV, a quality scan range of 50–600 amu, an ion source temperature of 230 °C, a quadrupole temperature of 150 °C, and a mass transmission line temperature of 280 °C.

2.4. Quantitative and OAV calculations of the volatile components

Series retrieval and manual analysis were performed on a mass spectrum diagram using the NIST11.L library, and a mass spectrum fitness of >90% was set as the substance identification standard. Ethyl decanoate was selected as the internal standard substance. The concentration of each volatile component was calculated using the equation $Ci = Cis \times Ai / Ais$, where Ci is the concentration of a particular substance (μg L^{-1}), Cis is the concentration of the internal standard substance (μg L^{-1}), Ai is the peak area of a particular substance, and Ais is the peak area of the internal standard substance. The OAVs of the volatile components were calculated using the equation $OAVi = Ci / Ti$, where Ci is the concentration of a particular substance (μg L^{-1}) and Ti is the odor detection threshold (μg L^{-1}) in Supplementary Table 2, derived from Schuh and Schieberle (2006), Campo et al. (2006), Czerny et al. (2008), Liu et al. (2016), and Zheng et al. (2017).

2.5. Data analysis

Analysis of variance and correlation analysis were performed using SPSS 17.0 (SPSS Inc., Chicago, IL, USA). Subsequently, PCA and OPLS-DA were performed using SIMCA-P 13 (Umetrics, Umea, Sweden).

3. Results and discussion

3.1. Analysis of volatile component contents of green tea from various tea cultivars

HS-SPME-GC-MS was used to identify the volatile components of the green tea produced from the 20 tea cultivars (Table 1). A total of 57 major volatile components were detected, and of those, 39 were detected in all of the samples and were thus deemed common volatile components. The total volatile components varied from 67.15 ± 2.39 μg L^{-1} to 236.63 ± 9.84 μg L^{-1} in the green tea from the 20 tea cultivars, varying considerably among these tea cultivars. For example, the total volatile component of CX1 was nearly 4 times higher than that of LLX. Table 1 indicates that linalool (2.61 ± 0.25 to 42.17 ± 1.66 μg L^{-1}), nonanal (8.41 ± 0.16 to 25.63 ± 1.87 μg L^{-1}), and geraniol (1.62 ± 0.74 to 38.76 ± 3.87 μg L^{-1}) were the most prevalent of the volatile components, followed by dimethyl sulfide (3.77 ± 0.99 to 15.64 ± 0.53 μg L^{-1}), methyl salicylate (0.99 ± 0.23 to 25.08 ± 1.89 μg L^{-1}), heptanal (2.55 ± 0.71 to 8.62 ± 1.32 μg L^{-1}), and caproicacidhexneylester (0.84 ± 0.20 to 15.63 ± 1.32 μg L^{-1}). Previous studies identified linalool, nonanal, and geraniol as the main substances that emit a floral or fruity flavor in green tea and as critical indicators of green tea aroma quality (Cheng et al., 2008; Liu et al., 2018). Dimethyl sulfide is a major factor in green tea aroma (Liu et al., 2016), whereas caproicacidhexneylester is a major factor in new tea aroma (Takei et al., 1976). The results obtained in this study support these previously reported results. In the present study, high levels of methyl salicylate and heptanal were detected in the samples. High levels of these components were not reported in previous studies; this difference in the results may have been caused by differences in the cultivation environment or processing techniques between the present study and previous studies.

Table 1 indicates that the contents of various substances in the volatile components varied substantially among the tea cultivars. For example, the linalool content in CX1 and ZX8 was 42.17 ± 1.66 μg L^{-1} and 36.04 ± 3.21 μg L^{-1}, respectively, which was significantly higher than those in other tea cultivars; the respective linalool content in YXZ and ZH2 was merely 2.61 ± 0.25 μg L^{-1} and 2.97 ± 0.29 μg L^{-1}. We speculated that the differences were caused primarily by the different expressions of the linalool synthase gene in the leaves of these tea cultivars (Liu et al., 2018). CX1 contained the most geraniol and methyl salicylate, whereas ZH2 contained the least geraniol and methyl salicylate. LS3 also contained high methyl salicylate content. LLX and YXZ contained only 0.84 ± 0.20 μg L^{-1} and 1.10 ± 0.29 μg L^{-1} caproicacidhexneylester, respectively, and these contents were significantly lower than those of the other tea cultivars. The nonanal, dimethyl sulfide, and heptanal contents also differed among the tea cultivars; however, these differences were less significant. For substances with a lower level of volatile components, differences were also observed among the tea cultivars. For instance, CX1 contained 6.84 ± 0.08 μg L^{-1}, 5.01 ± 0.59 μg L^{-1}, and 1.68 ± 0.02 μg L^{-1} cis-linalool oxide, 3-carene, and (E)-β-ocimene, respectively, and these contents were significantly higher than those in the other tea cultivars. YL1 contained relatively high methyl geranate (8.74 ± 1.21 μg L^{-1}) and 2,6-dimethyl-5-heptenal (5.86 ± 0.29 μg L^{-1}) contents; MH201 contained 15.68 ± 0.86 μg L^{-1} (E)-hex-3-enyl butyrate, which was significantly more than other tea cultivars; BY1 contained significantly more allyl-2-ethylbutyrate (6.39 ± 0.23 μg L^{-1}) and benzaldehyde (1.25 ± 0.20 μg L^{-1}) than the other tea cultivars; FD contained the most β-ionone and 2,4-di-tert-butylphenol; YXZ, MH201, CN98, and LS3 contained relatively high δ-cadinene

Table 1. Analysis of the volatile component contents of green tea from the various tea cultivars (μg L^{-1}).

No.	Aroma component	ZX8	ZH2	ZH1	YL1	YXZ	YX1	TRI19	SYH	SC1	NW106	MH201	LS3	LLX	GN02	EC12	EC11	CN98	CX1	BY1	FD
1	Linalool	36.04 ± 3.21	2.97 ± 0.29	31.60 ± 1.26	21.64 ± 3.28	2.61 ± 0.25	11.89 ± 0.82	13.57 ± 1.74	20.11 ± 2.85	14.81 ± 1.57	15.59 ± 1.93	12.11 ± 2.22	35.08 ± 3.48	6.08 ± 0.05	24.69 ± 1.04	15.03 ± 1.29	10.53 ± 0.89	8.98 ± 2.32	42.17 ± 1.66	16.14 ± 0.95	14.53 ± 1.28
2	Nonanal	25.63 ± 1.87	12.80 ± 0.19	22.87 ± 2.28	18.20 ± 0.65	8.41 ± 0.16	9.84 ± 1.11	12.33 ± 1.23	19.55 ± 2.35	12.98 ± 0.64	15.92 ± 1.38	16.33 ± 2.34	18.30 ± 1.98	9.54 ± 0.88	16.67 ± 0.99	17.92 ± 2.57	13.69 ± 1.19	11.05 ± 0.91	15.74 ± 1.78	19.90 ± 1.54	9.70 ± 0.83
3	Geraniol	16.35 ± 1.96	1.62 ± 0.74	10.42 ± 1.08	22.97 ± 1.39	11.40 ± 2.46	5.69 ± 0.86	13.95 ± 3.18	11.97 ± 0.90	13.07 ± 1.11	10.54 ± 1.33	9.73 ± 2.95	19.22 ± 1.86	7.39 ± 1.71	10.70 ± 2.36	13.35 ± 1.16	7.72 ± 1.03	8.17 ± 0.88	38.76 ± 3.87	18.60 ± 0.56	5.30 ± 0.67
4	Dimethyl sulfide	6.84 ± 0.73	11.39 ± 1.66	11.74 ± 0.69	5.37 ± 0.29	15.02 ± 1.79	9.39 ± 2.74	3.77 ± 0.99	4.30 ± 1.25	2.28 ± 0.48	8.90 ± 1.22	5.38 ± 0.68	6.48 ± 1.20	7.46 ± 0.74	15.64 ± 0.53	7.84 ± 1.54	10.46 ± 0.60	8.35 ± 0.94	13.95 ± 2.35	11.15 ± 1.70	11.24 ± 0.77
5	Methyl salicylate	7.59 ± 1.21	0.99 ± 0.23	5.29 ± 0.88	3.30 ± 0.56	4.00 ± 0.68	3.16 ± 0.29	3.30 ± 1.03	6.01 ± 1.28	4.63 ± 0.67	4.25 ± 0.35	3.23 ± 0.46	22.28 ± 3.87	1.68 ± 0.22	2.93 ± 0.91	4.29 ± 0.70	1.51 ± 0.33	4.37 ± 0.54	25.08 ± 1.89	4.98 ± 0.11	2.36 ± 0.26
6	Heptanal	7.15 ± 0.94	6.71 ± 1.28	7.93 ± 0.69	4.86 ± 0.80	6.24 ± 0.57	4.72 ± 0.63	2.55 ± 0.37	8.62 ± 1.32	2.66 ± 0.71	5.35 ± 1.05	8.56 ± 1.80	6.92 ± 2.21	3.15 ± 0.52	4.53 ± 0.90	4.95 ± 1.24	4.95 ± 0.32	4.79 ± 0.81	6.00 ± 0.52	7.70 ± 1.44	5.53 ± 0.73
7	Caproicacidhexneylester	13.46 ± 1.27	1.88 ± 0.71	5.01 ± 0.28	11.31 ± 0.33	1.10 ± 0.29	3.39 ± 0.67	1.88 ± 0.49	4.15 ± 0.86	3.16 ± 0.57	2.85 ± 0.29	12.81 ± 1.81	9.97 ± 0.11	0.84 ± 0.20	3.75 ± 0.36	4.10 ± 0.38	6.29 ± 0.85	2.43 ± 0.44	15.63 ± 1.32	4.84 ± 0.27	3.05 ± 0.83
8	Hexaldehyde	4.38 ± 0.42	4.58 ± 0.38	6.94 ± 0.73	4.28 ± 0.46	3.00 ± 0.34	3.56 ± 0.28	2.09 ± 0.31	4.84 ± 0.12	4.16 ± 0.79	4.90 ± 0.95	5.24 ± 0.82	4.32 ± 0.42	2.46 ± 0.22	6.07 ± 0.98	4.83 ± 1.12	3.57 ± 0.66	3.90 ± 0.22	6.40 ± 1.45	6.46 ± 0.84	4.70 ± 0.71
9	Capraldehyde	4.76 ± 0.51	3.01 ± 0.59	6.53 ± 0.82	5.23 ± 0.93	2.69 ± 0.28	2.86 ± 0.29	2.44 ± 0.41	4.70 ± 0.73	3.94 ± 0.84	3.98 ± 0.35	5.93 ± 0.78	4.76 ± 0.69	3.41 ± 0.37	6.92 ± 0.87	5.72 ± 0.23	3.53 ± 0.21	3.29 ± 0.44	5.28 ± 0.31	7.21 ± 0.39	3.02 ± 0.26
10	(E)-Hex-3-enyl butyrate	2.08 ± 0.32	0.47 ± 0.08	1.42 ± 0.22	8.27 ± 1.33	0.40 ± 0.25	1.50 ± 0.37	0.17 ± 0.10	3.33 ± 0.38	5.00 ± 0.22	0.69 ± 0.31	15.68 ± 0.86	3.69 ± 0.53	0.46 ± 0.09	7.36 ± 0.18	0.86 ± 0.09	1.83 ± 0.51	0.35 ± 0.10	7.81 ± 0.66	1.12 ± 0.20	0.53 ± 0.12
11	Toluene	2.24 ± 0.26	3.63 ± 0.55	3.61 ± 0.36	2.54 ± 0.26	2.86 ± 0.10	3.48 ± 0.39	1.44 ± 0.54	4.23 ± 0.29	1.62 ± 0.57	2.83 ± 0.21	3.37 ± 0.66	3.11 ± 0.27	1.62 ± 0.27	3.22 ± 0.53	2.81 ± 0.44	2.29 ± 0.66	2.89 ± 0.14	1.91 ± 0.08	4.29 ± 0.77	4.16 ± 0.14
12	P-xylene	2.73 ± 0.29	2.49 ± 0.12	4.27 ± 1.02	2.76 ± 0.21	1.92 ± 0.11	2.39 ± 0.33	1.24 ± 0.59	4.68 ± 0.19	1.19 ± 0.10	2.03 ± 0.08	3.52 ± 0.38	2.38 ± 0.27	1.60 ± 0.07	3.14 ± 0.33	2.14 ± 0.09	2.01 ± 0.27	1.96 ± 0.22	1.64 ± 0.10	3.23 ± 0.28	3.31 ± 0.20
13	2,4-Di-tert-butylphenol	1.43 ± 0.11	1.12 ± 0.22	2.66 ± 0.41	2.53 ± 0.29	1.66 ± 0.17	1.74 ± 0.08	0.84 ± 0.09	2.23 ± 0.39	0.82 ± 0.10	2.45 ± 0.11	2.77 ± 0.62	2.60 ± 0.35	1.00 ± 0.10	5.91 ± 0.18	2.16 ± 0.14	1.30 ± 0.13	1.21 ± 0.17	2.14 ± 0.28	3.72 ± 0.36	6.36 ± 0.47
14	Allyl-2-ethylbutyrate	1.54 ± 0.52	3.06 ± 0.44	3.77 ± 0.23	1.80 ± 0.09	1.71 ± 0.12	3.04 ± 0.31	0.81 ± 0.14	4.18 ± 0.25	0.96 ± 0.10	1.81 ± 0.17	2.98 ± 0.28	1.87 ± 0.32	0.61 ± 0.22	1.90 ± 0.41	2.26 ± 0.38	1.02 ± 0.12	1.29 ± 0.10	1.53 ± 0.17	6.39 ± 0.23	3.53 ± 0.26
15	2,3-Octadione	1.53 ± 0.16	3.73 ± 0.28	3.43 ± 0.93	1.57 ± 0.14	1.78 ± 0.32	3.17 ± 0.40	1.10 ± 0.11	3.08 ± 0.23	1.31 ± 0.18	1.50 ± 0.17	2.95 ± 0.68	1.62 ± 0.27	0.95 ± 0.33	1.84 ± 0.17	2.12 ± 0.45	1.09 ± 0.10	1.70 ± 0.13	1.49 ± 0.13	5.23 ± 0.36	2.15 ± 0.29
16	Naphthalene	1.70 ± 0.13	2.17 ± 0.36	3.26 ± 0.72	2.06 ± 0.18	1.52 ± 0.11	2.52 ± 0.25	1.31 ± 0.31	2.78 ± 0.53	1.93 ± 0.15	2.03 ± 0.20	2.58 ± 0.34	2.51 ± 0.20	1.38 ± 0.11	2.31 ± 0.41	2.65 ± 0.17	1.52 ± 0.10	1.62 ± 0.18	2.00 ± 0.24	2.69 ± 0.35	2.34 ± 0.66
17	α-Cedrene	1.35 ± 0.27	1.18 ± 0.11	2.43 ± 0.23	1.97 ± 0.19	1.70 ± 0.12	1.45 ± 0.12	0.96 ± 0.23	1.79 ± 0.18	2.00 ± 0.10	2.03 ± 0.11	2.55 ± 0.38	2.27 ± 0.31	1.03 ± 0.21	3.16 ± 0.35	2.09 ± 0.17	1.02 ± 0.10	1.38 ± 0.14	1.89 ± 0.18	2.92 ± 0.09	3.94 ± 0.30
18	Geranylacetone	1.32 ± 0.09	1.11 ± 0.13	2.29 ± 0.08	2.04 ± 0.25	1.57 ± 0.17	1.50 ± 0.17	0.76 ± 0.21	2.05 ± 0.13	0.89 ± 0.07	1.86 ± 0.15	2.16 ± 0.44	2.41 ± 0.27	0.92 ± 0.10	3.77 ± 0.28	1.79 ± 0.19	1.10 ± 0.08	1.17 ± 0.07	1.69 ± 0.11	3.28 ± 0.38	3.51 ± 0.23
19	δ-Cadinene	2.02 ± 0.15	0.53 ± 0.10	0.55 ± 0.14	0.90 ± 0.08	4.23 ± 0.34	0.39 ± 0.17	0.25 ± 0.08	0.79 ± 0.07	1.75 ± 0.27	0.92 ± 0.32	3.53 ± 0.78	3.93 ± 0.29	1.81 ± 0.08	1.39 ± 0.04	0.57 ± 0.08	2.76 ± 0.53	3.46 ± 0.24	0.90 ± 0.20	1.16 ± 0.11	1.81 ± 0.19
20	Cis-linalool oxide	3.68 ± 0.35	0.34 ± 0.09	0.85 ± 0.11	1.52 ± 0.19	1.11 ± 0.26	2.48 ± 0.37	1.68 ± 0.18	2.22 ± 0.31	0.86 ± 0.22	1.11 ± 0.10	1.13 ± 0.17	2.67 ± 0.24	0.48 ± 0.10	1.16 ± 0.15	1.13 ± 0.10	0.40 ± 0.18	0.43 ± 0.05	6.84 ± 0.08	1.92 ± 0.23	1.21 ± 0.09
21	Indole	2.55 ± 0.56	-	0.81 ± 0.13	-	-	-	-	4.94 ± 0.59	3.24 ± 0.33	-	4.46 ± 0.27	3.03 ± 0.10	-	3.52 ± 0.17	1.46 ± 0.14	1.61 ± 0.12	-	3.66 ± 0.21	1.10 ± 0.08	1.86 ± 0.15
22	3-carene	1.71 ± 0.14	0.50 ± 0.10	2.14 ± 0.35	1.97 ± 0.17	0.58 ± 0.11	1.10 ± 0.12	0.99 ± 0.17	1.17 ± 0.10	1.65 ± 0.13	1.07 ± 0.08	1.31 ± 0.07	3.29 ± 0.23	0.74 ± 0.09	2.24 ± 0.14	1.49 ± 0.25	1.33 ± 0.08	0.79 ± 0.20	5.01 ± 0.59	2.02 ± 0.43	0.84 ± 0.21
23	Octanal	3.07 ± 0.33	1.50 ± 0.14	1.90 ± 0.19	2.34 ± 0.24	0.93 ± 0.32	0.71 ± 0.08	1.11 ± 0.10	2.70 ± 0.27	0.66 ± 0.09	1.44 ± 0.31	1.62 ± 0.25	2.45 ± 0.09	0.59 ± 0.17	1.50 ± 0.13	1.36 ± 0.17	0.96 ± 0.23	1.43 ± 0.10	1.06 ± 0.10	1.95 ± 0.09	0.97 ± 0.07
No.	Aroma component	ZX8	ZH2	ZH1	YL1	YXZ	YX1	TRI19	SYH	SC1	NW106	MH201	LS3	LLX	GN02	EC12	EC11	CN98	CX1	BY1	FD

Table 1. Continued.

24	β-Ionone	0.80 ± 0.20	0.38 ± 0.16	1.50 ± 0.10	1.32 ± 0.13	2.10 ± 0.22	1.09 ± 0.10	0.41 ± 0.17	1.01 ± 0.33	0.40 ± 0.08	2.03 ± 0.08	1.27 ± 0.11	1.15 ± 0.07	0.48 ± 0.17	2.43 ± 0.19	0.98 ± 0.24	0.46 ± 0.11	0.75 ± 0.17	0.98 ± 0.14	1.64 ± 0.13	7.48 ± 0.29
25	m-Xylene	1.38 ± 0.11	1.75 ± 0.08	2.94 ± 0.27	1.15 ± 0.09	0.86 ± 0.18	1.25 ± 0.21	0.68 ± 0.10	2.34 ± 0.27	0.71 ± 0.13	1.11 ± 0.15	2.05 ± 0.24	1.31 ± 0.07	0.76 ± 0.07	1.68 ± 0.18	1.53 ± 0.14	1.04 ± 0.10	1.09 ± 0.07	1.15 ± 0.26	1.76 ± 0.30	1.65 ± 0.14
26	Methyl heptenone	1.03 ± 0.09	1.74 ± 0.13	1.74 ± 0.21	3.53 ± 0.34	1.02 ± 0.08	1.36 ± 0.17	0.65 ± 0.34	1.67 ± 0.16	1.11 ± 0.07	0.95 ± 0.23	1.75 ± 0.04	1.58 ± 0.08	0.58 ± 0.08	1.37 ± 0.17	1.29 ± 0.35	0.82 ± 0.22	0.91 ± 0.10	1.12 ± 0.11	2.40 ± 0.19	1.14 ± 0.21
27	Pentanal	2.50 ± 0.27	-	2.72 ± 0.28	-	0.99 ± 0.22	3.28 ± 0.10	0.79 ± 0.17	0.65 ± 0.08	-	2.24 ± 0.07	3.03 ± 0.43	3.04 ± 0.09	0.68 ± 0.10	-	1.63 ± 0.24	-	-	0.27 ± 0.13	3.43 ± 0.42	1.80 ± 0.08
28	(Z)-3-Cis-3-hexenyl isovalerate	3.82 ± 0.36	0.16 ± 0.12	1.35 ± 0.10	1.11 ± 0.09	0.40 ± 0.14	1.29 ± 0.11	0.55 ± 0.05	1.71 ± 0.09	0.18 ± 0.07	1.12 ± 0.09	3.18 ± 0.25	3.87 ± 0.38	0.22 ± 0.14	0.55 ± 0.09	0.40 ± 0.17	1.15 ± 0.16	0.88 ± 0.15	2.68 ± 0.36	2.24 ± 0.27	-
29	(2Z)-2-Octene-1-ol	0.72 ± 0.12	1.10 ± 0.09	1.58 ± 0.11	1.38 ± 0.24	0.62 ± 0.18	0.96 ± 0.20	0.37 ± 0.22	1.15 ± 0.17	1.48 ± 0.35	0.89 ± 0.27	1.60 ± 0.17	1.80 ± 0.15	0.35 ± 0.08	1.18 ± 0.07	0.87 ± 0.10	1.11 ± 0.17	0.76 ± 0.38	1.13 ± 0.07	2.82 ± 0.13	0.90 ± 0.14
30	2,2,6-Trimethyl-6-vinyltetrahydro-2H-pyran-3-ol	1.68 ± 0.09	0.57 ± 0.07	0.81 ± 0.09	1.08 ± 0.10	1.04 ± 0.17	2.59 ± 0.12	0.62 ± 0.07	1.66 ± 0.04	0.24 ± 0.07	1.10 ± 0.08	1.13 ± 0.12	0.81 ± 0.18	0.70 ± 0.14	0.99 ± 0.13	1.22 ± 0.24	0.54 ± 0.17	0.37 ± 0.07	1.18 ± 0.31	1.61 ± 0.19	2.48 ± 0.34
31	Ethylbenzene	1.29 ± 0.08	0.92 ± 0.11	1.35 ± 0.17	1.38 ± 0.23	0.57 ± 0.15	1.02 ± 0.10	0.43 ± 0.07	2.36 ± 0.04	0.68 ± 0.05	0.68 ± 0.09	2.11 ± 0.27	0.92 ± 0.32	0.65 ± 0.08	1.29 ± 0.09	0.96 ± 0.11	0.90 ± 0.14	0.77 ± 0.13	0.54 ± 0.24	1.05 ± 0.10	1.42 ± 0.17
32	β-Cyclocitral	0.93 ± 0.24	0.36 ± 0.21	1.56 ± 0.08	1.25 ± 0.17	0.99 ± 0.09	0.86 ± 0.12	0.48 ± 0.09	1.28 ± 0.14	0.50 ± 0.07	1.09 ± 0.05	0.99 ± 0.23	1.03 ± 0.06	0.38 ± 0.07	1.65 ± 0.09	0.84 ± 0.10	0.48 ± 0.23	0.79 ± 0.09	0.84 ± 0.11	1.27 ± 0.17	0.88 ± 0.06
33	2,6-Di-tert-butyl-p-benzoquinone	0.64 ± 0.08	0.45 ± 0.07	1.01 ± 0.13	0.89 ± 0.14	0.88 ± 0.17	0.56 ± 0.10	0.25 ± 0.11	0.56 ± 0.12	0.39 ± 0.10	1.04 ± 0.19	1.07 ± 0.17	0.82 ± 0.14	0.44 ± 0.15	1.94 ± 0.13	0.83 ± 0.09	0.52 ± 0.08	0.49 ± 0.04	0.73 ± 0.07	1.37 ± 0.17	2.21± 0.35
34	Safranal	0.94 ± 0.09	0.58 ± 0.10	2.05 ± 0.31	0.63 ± 0.22	0.67 ± 0.07	0.67 ± 0.06	0.23 ± 0.05	1.02 ± 0.18	0.35 ± 0.09	0.88 ± 0.20	0.90 ± 0.10	0.58 ± 0.11	0.28 ± 0.04	1.63 ± 0.09	0.54 ± 0.07	0.35 ± 0.10	0.56 ± 0.07	1.02 ± 0.08	1.26 ± 0.24	0.61± 0.05
35	Phenethyl alcohol	0.58 ± 0.07	0.63 ± 0.07	0.57 ± 0.04	0.89 ± 0.07	0.10 ± 0.04	1.16 ± 0.09	0.43 ± 0.05	1.09 ± 0.27	-	0.78 ± 0.11	0.33 ± 0.08	0.67 ± 0.31	0.68 ± 0.05	0.86 ± 0.08	0.79 ± 0.09	1.20 ± 0.10	0.35 ± 0.11	2.31 ± 0.36	0.63 ± 0.13	1.22 ± 0.21
36	Limonene	0.83 ± 0.11	0.20 ± 0.01	1.04 ± 0.17	1.17 ± 0.14	0.44 ± 0.07	0.51 ± 0.04	0.60 ± 0.03	0.63 ± 0.10	0.75 ± 0.09	0.72 ± 0.05	0.72 ± 0.08	1.10 ± 0.07	0.36 ± 0.17	0.94 ± 0.04	0.73 ± 0.04	0.48 ± 0.11	0.59 ± 0.03	1.92 ± 0.37	0.94 ± 0.12	0.46 ± 0.03
37	(Z,Z)-3-Hexenoicacid-3-hexenylester,	1.36 ± 0.23	0.22 ± 0.02	0.80 ± 0.11	1.85 ± 0.27	-	0.81 ± 0.14	0.17 ± 0.08	0.48 ± 0.07	0.50 ± 0.02	-	0.89 ± 0.09	1.45 ± 0.07	0.11 ± 0.02	0.60 ± 0.10	0.62 ± 0.17	0.55 ± 0.01	0.30 ± 0.04	1.20 ± 0.19	0.68 ± 0.21	1.79 ± 0.30
38	2-Methylbutyraldehyde	0.59 ± 0.09	1.02 ± 0.11	0.80 ± 0.03	0.50 ± 0.04	0.35 ± 0.01	1.06 ± 0.07	0.50 ± 0.17	0.59 ± 0.14	-	0.69 ± 0.19	0.14 ± 0.04	0.54 ± 0.05	0.71 ± 0.17	1.14 ± 0.28	0.96 ± 0.11	0.83 ± 0.13	0.76 ± 0.07	0.74 ± 0.05	1.07 ± 0.22	0.68 ± 0.10
39	Hyacinthin	0.44 ± 0.13	0.51 ± 0.03	0.83 ± 0.14	0.65 ± 0.10	0.39 ± 0.04	0.79 ± 0.09	0.57 ± 0.09	0.43 ± 0.04	0.68 ± 0.07	0.73 ± 0.04	0.26 ± 0.10	0.28 ± 0.04	0.70 ± 0.17	0.65 ± 0.04	1.37 ± 0.21	0.28 ± 0.01	0.71 ± 0.05	1.10 ± 0.12	1.75 ± 0.18	0.59 ± 0.04
40	Methyl geranate	-	-	-	8.74 ± 1.21	-	0.27 ± 0.07	0.10 ± 0.04	0.75 ± 0.11	0.10 ± 0.05	0.33 ± 0.09	0.37 ± 0.04	0.47 ± 0.07	0.18 ± 0.03	-	0.11 ± 0.04	-	0.20 ± 0.03	0.34 ± 0.07	1.15 ± 0.22	-
41	Benzyl alcohol	0.62 ± 0.21	0.66 ± 0.07	0.99 ± 0.08	0.51 ± 0.05	0.45 ± 0.04	0.58 ± 0.05	0.16 ± 0.02	0.51 ± 0.04	0.15 ± 0.05	0.60 ± 0.13	0.43 ± 0.09	0.75 ± 0.08	0.47 ± 0.10	0.48 ± 0.05	0.54 ± 0.11	0.73 ± 0.12	0.96 ± 0.07	0.90 ± 0.08	0.69 ± 0.10	0.97 ± 0.18
42	2,6-Dimethyl-5-heptenal	-	0.10 ± 0.08	0.17 ± 0.10	5.86 ± 0.29	-	0.25 ± 0.07	-	0.30 ± 0.07	0.39 ± 0.04	0.21 ± 0.05	0.23 ± 0.03	0.33 ± 0.03	0.13 ± 0.04	1.44 ± 0.19	0.85 ± 0.09	0.18 ± 0.05	0.24 ± 0.07	0.59 ± 0.07	0.59 ± 0.09	0.16 ± 0.11
43	Benzaldehyde	0.43 ± 0.08	0.52 ± 0.14	0.88 ± 0.09	0.53 ± 0.07	0.38 ± 0.04	0.86 ± 0.10	0.36 ± 0.13	0.60 ± 0.08	0.66 ± 0.05	0.51 ± 0.07	0.50 ± 0.04	0.70 ± 0.11	0.33 ± 0.10	0.70 ± 0.16	0.59 ± 0.07	0.34 ± 0.04	0.54 ± 0.03	0.64 ± 0.09	1.25 ± 0.20	0.57 ± 0.02
44	Styrene	0.49 ± 0.08	0.80 ± 0.17	1.22 ± 0.11	0.39 ± 0.03	0.38 ± 0.03	0.52 ± 0.08	0.38 ± 0.04	0.50 ± 0.03	0.27 ± 0.10	0.73 ± 0.09	0.79 ± 0.07	0.52 ± 0.06	0.28 ± 0.01	0.50 ± 0.02	0.78 ± 0.14	0.38 ± 0.02	0.50 ± 0.13	0.43 ± 0.08	0.87 ± 0.05	0.47 ± 0.05
45	2-Methylnaphthalene	0.38 ± 0.07	0.44 ± 0.04	0.97 ± 0.17	0.64 ± 0.05	0.39 ± 0.04	0.63 ± 0.04	0.26 ± 0.04	0.64 ± 0.09	0.29 ± 0.02	-	0.53 ± 0.05	0.61 ± 0.04	0.27 ± 0.04	0.90 ± 0.10	0.58 ± 0.05	0.29 ± 0.02	0.34 ± 0.03	0.51 ± 0.05	1.16 ± 0.13	1.30 ± 0.09
46	Citral	0.53 ± 0.14	-	0.58 ± 0.13	1.35 ± 0.28	0.58 ± 0.08	0.32 ± 0.03	0.44 ± 0.03	0.57 ± 0.03	0.67 ± 0.09	0.55 ± 0.05	0.53 ± 0.05	0.80 ± 0.05	0.22 ± 0.07	0.67 ± 0.07	0.49 ± 0.05	0.23 ± 0.10	0.26 ± 0.02	1.53 ± 0.31	0.57 ± 0.06	-
47	(E)-β-Ocimene	0.59 ± 0.14	-	0.60 ± 0.03	0.87 ± 0.06	0.33 ± 0.03	0.23 ± 0.03	0.74 ± 0.09	0.34 ± 0.03	0.46 ± 0.03	0.41 ± 0.07	0.40 ± 0.04	0.71 ± 0.04	0.23 ± 0.11	0.44 ± 0.05	0.47 ± 0.04	0.31 ± 0.04	0.28 ± 0.04	1.68 ± 0.02	0.57 ± 0.04	0.25 ± 0.01
48	Leaf alcohol	0.55 ± 0.17	-	0.17 ± 0.05	1.00 ± 0.21	0.44 ± 0.05	0.42 ± 0.05	0.21 ± 0.04	0.24 ± 0.04	0.15 ± 0.04	0.45 ± 0.03	0.41 ± 0.03	0.53 ± 0.07	0.30 ± 0.05	0.39 ± 0.04	0.44 ± 0.07	0.79 ± 0.04	0.48 ± 0.03	0.32 ± 0.02	-	1.18 ± 0.07

49	(E)-2-Nonenal	0.44 ± 0.05	0.27 ± 0.03	0.80 ± 0.10	0.49 ± 0.04	0.19 ± 0.04	0.19 ± 0.08	0.13 ± 0.04	0.39 ± 0.05	0.50 ± 0.04	0.35 ± 0.05	0.56 ± 0.04	0.44 ± 0.02	0.09 ± 0.02	0.52 ± 0.04	0.46 ± 0.04	0.24 ± 0.02	0.22 ± 0.02	0.62 ± 0.04	0.78 ± 0.04	0.32 ± 0.04
50	α-Terpineol	0.35 ± 0.06	0.12 ± 0.02	0.29 ± 0.02	0.65 ± 0.10	0.08 ± 0.03	0.24 ± 0.02	0.25 ± 0.05	0.30 ± 0.05	0.54 ± 0.03	0.34 ± 0.04	0.40 ± 0.02	0.54 ± 0.03	0.21 ± 0.04	0.66 ± 0.06	0.36 ± 0.09	0.24 ± 0.04	0.27 ± 0.03	0.68 ± 0.07	0.33 ± 0.03	0.45 ± 0.04
51	(E)-2-Heptenal	0.19 ± 0.05	0.25 ± 0.02	0.27 ± 0.02	0.39 ± 0.03	0.22 ± 0.03	0.26 ± 0.03	0.16 ± 0.03	0.22 ± 0.02	0.63 ± 0.03	0.40 ± 0.04	0.43 ± 0.03	0.53 ± 0.07	0.12 ± 0.06	0.32 ± 0.03	0.35 ± 0.08	0.40 ± 0.04	0.22 ± 0.07	0.46 ± 0.06	0.95 ± 0.07	0.28± 0.02
52	α-Cubebene	0.71 ± 0.15	0.10 ± 0.05	-	-	1.15 ± 0.24	0.14 ± 0.04	-	0.20 ± 0.06	0.43 ± 0.07	-	0.99 ± 0.09	1.48 ± 0.29	0.53 ± 0.07	-	-	0.66 ± 0.09	0.52 ± 0.05	-	-	-
53	Isovaleraldehyde	0.22 ± 0.11	0.44 ± 0.04	0.37 ± 0.04	-	-	0.49 ± 0.05	-	-	-	0.30 ± 0.02	0.09 ± 0.04	0.16 ± 0.02	0.35 ± 0.04	0.41 ± 0.05	0.42 ± 0.04	0.32 ± 0.07	0.40 ± 0.03	0.46 ± 0.06	0.68 ± 0.05	0.33 ± 0.02
54	Benzene	-	-	-	0.4 ± 0.06	-	-	-	-	-	0.48 ± 0.04	0.34 ± 0.05	-	-	-	-	-	2.75 ± 0.46	-	-	-
55	2,2,6-Trimethylcyclohexane-dione	-	-	-	0.32 ± 0.21	0.37 ± 0.03	0.29 ± 0.03	-	0.53 ± 0.04	-	-	0.19 ± 0.02	-	0.16 ± 0.06	-	0.10 ± 0.04	-	-	-	0.19 ± 0.03	-
56	α-Terpinene	0.24 ± 0.02	-	0.28 ± 0.02	0.31 ± 0.05	-	-	-	-	-	0.19 ± 0.03	0.12 ± 0.05	0.32 ± 0.07	-	-	0.10 ± 0.04	-	-	-	-	-
57	Methyl hexanoate	-	-	-	-	-	0.28 ± 0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total aroma component		176.36 ± 6.98	82.13 ± 4.26	171.97 ± 5.32	170.69 ± 2.18	92.82 ± 3.21	105.26 ± 5.94	79.47 ± 2.38	149.13 ± 4.97	98.81 ± 1.53	115.95 ± 6.45	158.66 ± 3.47	195.00 ± 1.56	67.15 ± 2.39	160.64 ± 1.83	125.14 ± 7.16	98.30 ± 5.58	93.23 ± 6.44	236.63 ± 9.84	173.70 ± 7.30	127.55 ± 2.33

-: <0.05 μg L^{-1} or not detected.

content; and YX1 contained a trace of methyl hexanoate content. These results demonstrated that the volatile components of the green tea produced from different tea cultivars varied substantially, and some green tea samples contained relatively high component contents that emitted unique aromas. These differences were caused primarily by the different contents and ratios of aroma component precursors in the leaves of the tea plants (Zhang et al., 2006; Wang et al., 2015; Wang et al., 2016).

3.2. Analysis of volatile component types of green tea produced from the various tea cultivars

The analysis of the 20 green tea samples revealed 57 volatile components, including 16 aldehydes, 9 alcohols, 8 esters, 8 alkenes, 7 aromatic hydrocarbons, 5 ketones, and other 4 components (Figure 2). Figure 2 indicates that aldehydes and alcohols accounted for the highest proportions, followed by esters; these 3 component types accounted for 54.61%–80.86% of each sample's volatile components and were therefore the major parts of the volatile components. Alcohols accounted for the highest and lowest proportions (39.85% and 9.77%) of CX1 and ZH2, respectively. Among the alcohols, linalool, geraniol, and cis-linalool oxide accounted for the highest proportions. For the 20 samples, aldehydes accounted for 18.06%–39.79% of the volatile components. Among the aldehydes, nonanal (which carried a rose flavor), heptanal (which carried a fruity flavor), hexaldehyde (which carried an apple flavor), and capraldehyde (which carried an orange flavor) accounted for relatively high proportions. Esters accounted for 6.10%–24.67% of the volatile components. Among the esters, methyl salicylate (which carried a wintergreen oil flavor), caproicacidhexneylester (which carried a fresh fruity flavor), (E)-hex-3-enyl butyrate (which carried an aromatic fruity flavor), and allyl-2-ethylbutyrate (which carried a fruit-like flavor) accounted for relatively high proportions. Although component types such as ketones, alkenes, and aromatic hydrocarbons accounted for lower proportions of the total volatile components, they still played key roles in aroma formation (Zhu et al., 2015; Liu et al., 2016). Among the ketones, 2,3-octadione (which carried a milky flavor), β-ionone (which carried a floral flavor), and geranylacetone (which carried a fresh flavor) accounted for relatively high proportions. Among the alkenes, δ-cadinene (which carried a woody flavor), 3-carene, and α-cedrene accounted for relatively high proportions. Among the aromatic hydrocarbons, toluene and p-xylene accounted for the highest proportions. Among the other compounds, dimethyl sulfide was a crucial and unique substance in the aroma component of fresh green tea. The 20 green tea samples tested all contained high proportions of dimethyl sulfide.

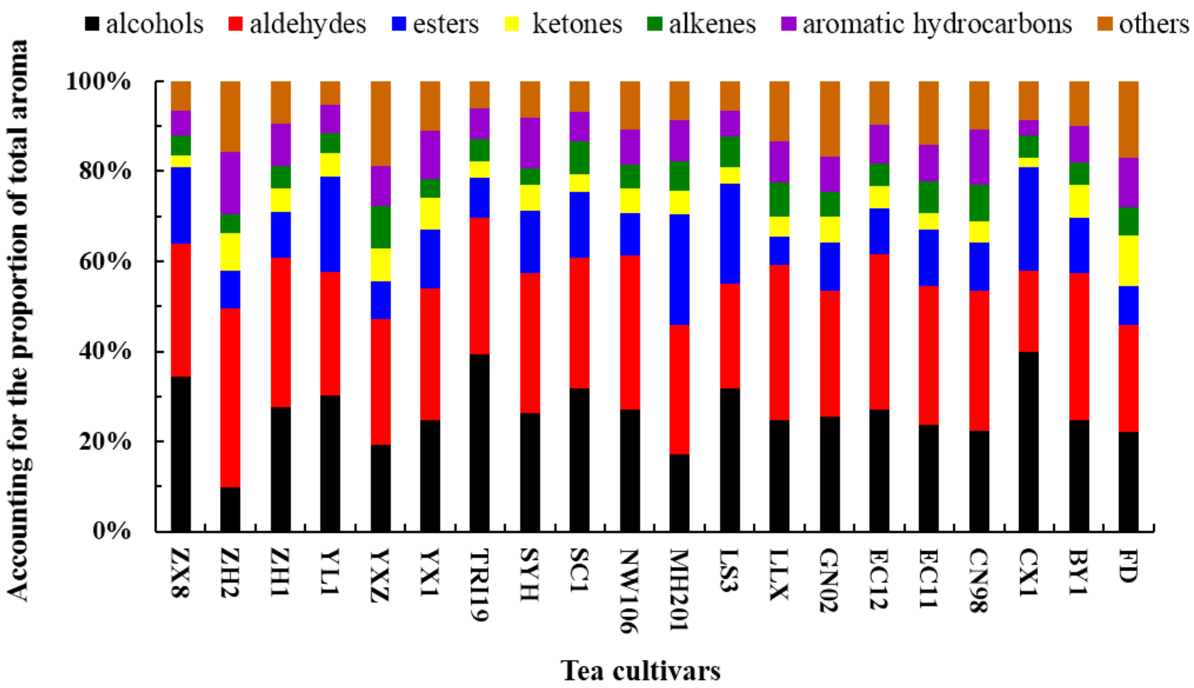

Figure 2. Analysis of volatile component types of green tea produced from the various tea cultivars.

3.3. Correlation analyses of aroma scores and volatile component contents of green tea produced from the various tea cultivars

A sensory evaluation of aroma was performed on the green tea samples from 20 tea cultivars, and the aromatic characteristics and aroma scores of the sensory evaluation are presented in Table 2. The results indicated that all of the samples emitted fresh, clean, and high aromas, which are typical characteristics of green tea. Aroma scores of the sensory evaluation were 90–95. Previous studies have revealed that tea cultivar is one of the main factors that determines tea aroma. Different tea cultivars grown in identical cultivation environments produced teas that emitted remarkably dissimilar aromas, despite identical processing techniques (Wang et al., 2010; Huang et al., 2016). As shown in Table 2, the floral and chestnut flavors of the green tea from the various tea cultivars were dissimilar. For example, CX1, EC12, YXZ, and NW106 emitted a floral flavor, whereas BY1, EC11, LS3, and CX1 emitted a chestnut flavor. YL1 and SC1, which exuded a sweet aroma, received relatively low aroma scores on the sensory evaluation.

A correlation analysis using SPSS was performed on the aroma score (Table 2) and volatile component contents (Table 1) to explore the correlations between the aroma quality and components for the green tea from various tea cultivars. As indicated in Table 3, an extremely significant correlation was identified between the aroma scores and linalool, geraniol, methyl salicylate, cis-linalool oxide, 3-carene, phenethyl alcohol, and limonene contents ($P < 0.01$), and a significant correlation was identified between the aroma scores and (Z)-3-cis-3-hexenyl isovalerate, citral, and (E)-β-ocimene contents ($P < 0.05$). An additional analysis was conducted on the correlation between the aroma scores and levels of volatile component types (e.g., alcohols, aldehydes, and esters). The results indicated that an extremely significant correlation was identified between the aroma scores and alcohols, as well as between the aroma scores and total volatile component contents, and a significant correlation was revealed between the aroma scores and ester and alkene contents.

3.4. OAV analysis of volatile components in green tea produced from the various tea cultivars

Studies have demonstrated that the odor detection thresholds of volatile components critically affect tea aroma (Liu et al., 2016). The OAV is based on both the volatile component contents and their odor detection threshold; this calculation more accurately represents the true effect of volatile components than one that considers only the volatile component contents (Campo et al., 2006; Schuh and Schieberle, 2006). OAVs may be used to assess the contribution of a component to the aroma of a substance. In general, a substance with an OAV of >1 directly affects the overall aroma (Czerny et al., 2008; Liu et al., 2016; Zheng et al., 2017). In this study, the OAV analysis was performed by investigating the

Table 2. Aroma characteristics and scores of green tea produced from the various tea cultivars.

Tea cultivar	Aroma characteristic	Aroma score
ZX8	Fresh and high	92.5
ZH2	Clean aroma	90
ZH1	More fresh and high	92
YL1	Clean and sweet	91
YXZ	Clean and high (with a slightly floral flavor)	92
YX1	Clean and high	92
TRI19	More clean and high (with a slight grass taste)	90.5
SYH	Fresh and high	93
SC1	Clean and high (sweet aroma)	91
NW106	Clean and high (with a slightly floral flavor)	93
MH201	Clean and high	91
LS3	High and brisk (chestnut flavor)	94
LLX	Clean and high	92
GN02	High and brisk	93
EC12	Fresh and high (floral flavor)	93
EC11	High and brisk (with a little chestnut flavor)	92.5
CN98	Clean and high	91
CX1	Clean and high (floral flavor, chestnut flavor)	95
BY1	Clean and high (with a slightly floral flavor)	92
FD	High and brisk	91.5

Table 3. Correlation analyses of the aroma scores and volatile component contents of the green tea produced from the various tea cultivars.

Component	Correlation coefficient
Linalool	0.664**
Geraniol	0.585**
Methyl salicylate	0.732**
Cis-linalool oxide	0.656**
3-Carene	0.715**
(Z)-3-Cis-3-hexenyl isovalerate	0.462*
Phenethyl alcohol	0.619**
Limonene	0.624**
Citral	0.499*
(E)-β-Ocimene	0.545*
Alcohols	0.694**
Esters	0.513*
Alkenes	0.550*
Total aroma component	0.624**

** $P < 0.01$, *$P < 0.05$.

aroma components of the green tea and odor detection thresholds of the tea's constituent substances. The results (Table 4) revealed 9 substances from the 20 green tea samples with relatively high OAVs. The substances, in descending order, were linalool, capraldehyde, dimethyl sulfide, β-ionone, geraniol, nonanal, heptanal, (E)-2-nonenal, and caproicacidhexneylester. These substances were similar to those with a high OAV in Huangshan Maofeng tea, which has a fresh flavor (Liu et al., 2016). Overall, CX1 exhibited a relatively high OAV, which was consistent with the description of the tea in the sensory evaluation (i.e. clear aroma with a chestnut flavor and a strong floral flavor). Compared with the other tea cultivars, ZH2 exhibited a lower OAV, which supported the results obtained from the sensory evaluation (i.e. low score and described as emitting a weak aroma). The OAVs of the volatile components varied among the green teas from the various tea cultivars. For example, compared with the other tea cultivars, the OAV of linalool in CX1, ZX8, and LS3 was higher and that in YXZ, ZH2, and LLX was significantly lower (i.e. 4.35, 4.94, and 10.13, respectively). Capraldehyde, which accounted for small proportions of the volatile components, displayed a relatively high

Table 4. OAV analysis of volatile components in green tea produced from the various tea cultivars.

Tea cultivar	Linalool	Capraldehyde	Dimethyl sulfide	β-Ionone	Geraniol	Nonanal	Heptanal	(E)-2-Nonenal	Caproicacidhexneylester
ZX8	60.07	47.58	6.22	3.99	5.11	3.20	2.38	1.09	1.35
ZH2	4.94	30.06	10.35	1.92	0.51	1.60	2.24	0.68	0.19
ZH1	52.66	65.35	10.68	7.49	3.26	2.86	2.64	2.01	0.50
YL1	36.07	52.30	4.89	6.62	7.18	2.27	1.62	1.23	1.13
YXZ	4.35	26.87	13.66	10.49	3.56	1.05	2.08	0.48	0.11
YX1	19.81	28.61	8.54	5.43	1.78	1.23	1.57	0.46	0.34
TRI19	22.61	24.39	3.43	2.07	4.36	1.54	0.85	0.32	0.19
SYH	33.52	47.05	3.91	5.06	3.74	2.44	2.87	0.97	0.41
SC1	24.68	39.39	2.07	2.01	4.08	1.62	0.89	1.24	0.32
NW106	25.98	39.84	8.09	10.15	3.30	1.99	1.78	0.87	0.29
MH201	20.18	59.32	4.89	6.34	3.04	2.04	2.85	1.39	1.28
LS3	58.47	47.64	5.89	5.73	6.01	2.29	2.31	1.09	1.00
LLX	10.13	34.10	6.78	2.41	2.31	1.19	1.05	0.23	0.08
GN02	41.15	69.19	14.22	12.15	3.34	2.08	1.51	1.30	0.38
EC12	25.05	57.17	7.12	4.89	4.17	2.24	1.65	1.14	0.41
EC11	17.55	35.35	9.51	2.30	2.41	1.71	1.65	0.60	0.63
CN98	14.97	32.86	7.59	3.76	2.55	1.38	1.60	0.56	0.24
CX1	70.28	52.79	12.68	4.89	12.11	1.97	2.00	1.55	1.56
BY1	26.91	72.10	10.14	8.20	5.81	2.49	2.57	1.95	0.48
FD	24.22	30.17	10.21	37.40	1.66	1.21	1.84	0.80	0.30

OAV in all of the green tea samples because of its low odor detection threshold. For example, the capraldehyde in BY1 exhibited an OAV of 72.10. By contrast, nonanal accounted for large proportions of the aroma components and exhibited a relatively low OAV in all of the green tea samples because of its high odor detection threshold. The OAV of β-ionone in FD was 37.40, which was significantly higher than its OAV in the other tea cultivars; the OAV of (E)-2-nonenal was >1 in 10 tea cultivars; the OAV of caproicacidhexneylester was >1 in ZX8, YL1, MH201, LS3, and CX15 only; the OAV of geraniol, (E)-2-nonenal, and caproicacidhexneylester was <1 in ZH2; and the OAV of heptanal in TRI19 and SC1 was <1.

3.5. PCA and OPLS-DA of green tea produced from the various tea cultivars

PCA and OPLS-DA are critical data analysis methods. Through generalization, organization, and statistical analysis of sample data, small changes, categories, and trends in the data can be objectively identified (Trygg et al., 2007; Szeto et al., 2010). In this study, PCA was performed on the volatile components of the green teas produced from the various tea cultivars using SIMCA-P 13 (Umetrics). As illustrated in Figure 3A, the 20 tea cultivars were divided into 6 categories according to the results. Category 1 contained SC1, EC11, CN98, TRI19, YXZ, and LLX; Category 2 contained NW106, EC12, YX1, and ZH2; Category 3 contained YL1, ZX8, and LS3; Category 4 contained MH201, SYH, GN02, and FD; Category 5 contained ZH1 and BY1; and Category 6 contained CX1. For tea cultivars in the same categories, the green tea volatile components were similar. For tea cultivars in different categories, further distance between the categories indicated greater dissimilarity in the green tea volatile components. To further understand the main volatile components of the green tea samples, SIMCA-P 13 was used to perform OPLS-DA on the volatile component contents of the green tea samples (Supplementary Figure 1), and the categorization results of the tea cultivars were similar to those obtained from the PCA. In the OPLS-DA load diagram, a small distance between the component and the starting point indicated a relatively small effect of the component on the sample cluster (Feng et al., 2014). Therefore, the data from Figure 3B demonstrated that the presence of relatively highly volatile component contents, including linalool, nonanal, and geraniol, substantially contributed to the tea cultivar categorization, whereas

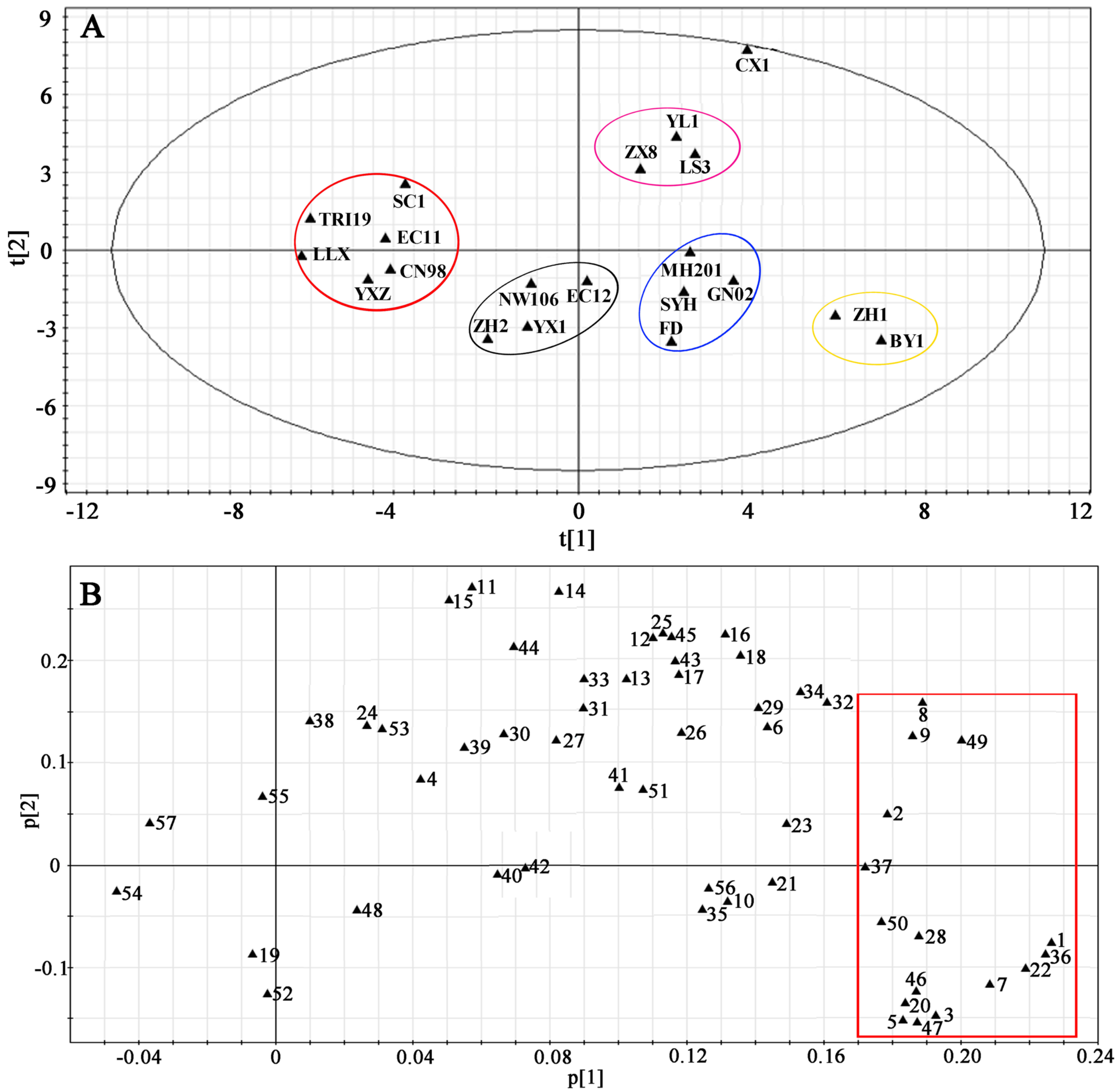

Figure 3. PCA score plot (A) and corresponding OPLS-DA loading plot (B) derived from the volatile component contents of the green tea produced from the various tea cultivars (numbers in Figure 3B are serial numbers of the aroma components in Table 1).

the presence of other relatively mildly volatile component contents contributed less profoundly to the tea cultivar categorization. Subsequently, a key variable analysis of the green tea volatile components was performed using the variable influence on projection (VIP) values generated in the OPLS-DA. In general, a component with a VIP of >1 was considered a key component (Li et al., 2015). As indicated by the data in Supplementary Table 3, a total of 23 volatile components exhibited VIP values of >1. Compared with the other volatile components, these volatile components contributed more to the categorization of the 20 tea cultivars. The volatile component contents (key components) varied considerably among the tea cultivars. Next, the effect of highly volatile component contents, including linalool, nonanal, geraniol, and so on, was more pronounced on the tea cultivar categorization than other mildly volatile component contents. Meanwhile, these highly volatile component contents were correlated with the aroma scores of sensory evaluation for the green tea samples from the 20 tea cultivars.

3.6. Conclusions

In this study, a sensory evaluation method and the HS-SPME-GC-MS method were employed to analyze and compare the aromatic characteristics and volatile components of green tea produced from the 20 tea cultivars. The analysis revealed 57 major volatile components in the tea samples. Aldehydes, alcohols, and esters were the most common component types in all of the samples (aldehydes and alcohols were even more prevalent than esters); together, the 3 component types accounted for 54.61%–80.86% of the volatile components of each tea. Other component types, such as alkenes and aromatic hydrocarbons, accounted for relatively lower proportions of the total volatile components. The total volatile component contents of the 20 green tea samples were between 67.15 ± 2.39 and 236.63 ± 9.84 $\mu g\ L^{-1}$, and linalool, nonanal, and geraniol were the main volatile components, followed by dimethyl sulfide, methyl salicylate, heptanal, and caproicacidhexneylester. However, the volatile component contents varied considerably among 20 green tea samples. Similarly, the minor volatile component contents differed among the tea samples. A correlation analysis was conducted to explore the correlations between the aroma scores and aroma component contents in the various tea samples. The results indicated a significant correlation between the aroma scores and linalool, geraniol, methyl salicylate, cis-linalool oxide, 3-carene, phenethyl alcohol, limonene, (Z)-3-cis-3-hexenyl isovalerate, citral, and (E)-β-ocimene contents. Another analysis indicated an extremely significant correlation between the aroma scores and alcohols, as well as between the aroma scores and total volatile component contents. Additionally, a significant correlation was identified between the aroma scores and ester and alkene contents. OAV analysis, PCA, and OPLS-DA were performed on the aroma components to systematically identify the main substances that emitted the aromas and substances that contributed to key aroma differences. The results revealed 9 substances with a relatively high OAV. The volatile components with the highest OAV were, in descending order, linalool, capraldehyde, dimethyl sulfide, β-ionone, geraniol, nonanal, heptanal, (E)-2-nonenal, and caproicacidhexneylester. These substances played crucial roles in forming green tea aromas. The PCA and OPLS-DA indicated that the 20 tea cultivars could be divided into 6 categories, where tea cultivars in the same categories exhibited similar green tea volatile components. Distances between categories corresponded to the degree of dissimilarity in the corresponding tea volatile components. Highly volatile component contents, including linalool, nonanal, geraniol, and so on, considerably influenced categorization, whereas other mildly volatile component contents contributed less to tea cultivar categorization. A key variable analysis of the green tea volatile components was performed using the VIP values generated in the OPLS-DA, and the results indicated that 23 volatile components were relatively influential in the categorization of the green tea produced from the various tea cultivars.

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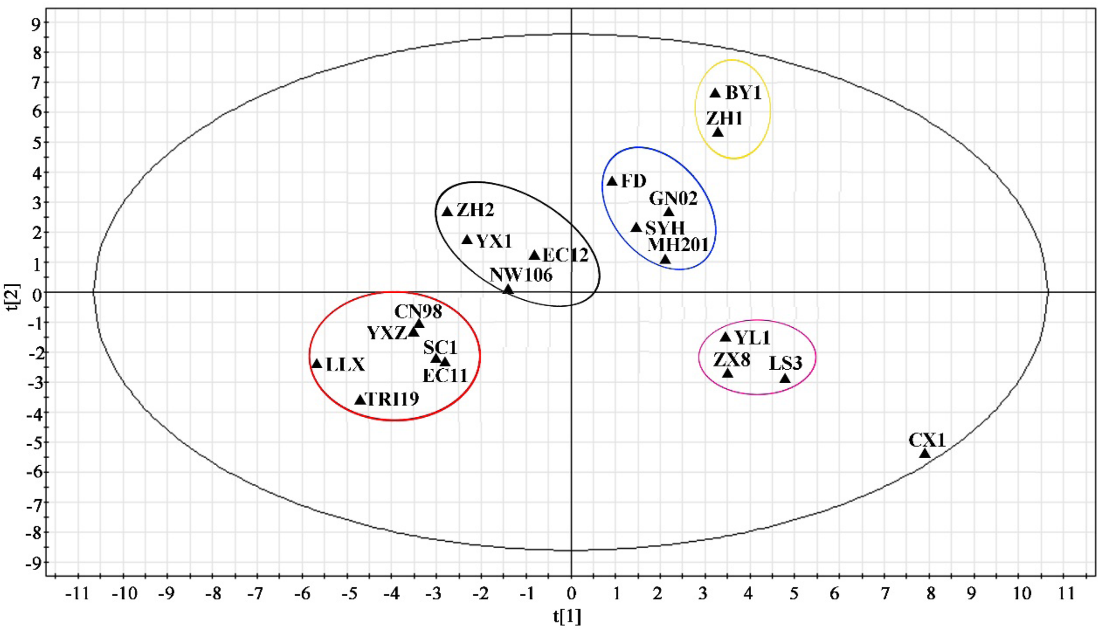
Supplementary Table 1. Details of the 20 tea cultivars.

Tea cultivars	Shape characteristics of green tea	Breeding institutes	Origin
C. sinensis L. 'Zhongxuan 8' (ZX8)	Slightly dark jade green	Tea Research Institute, Chinese Academy of Agricultural Sciences	Hangzhou, Zhejiang
C. sinensis L. 'Zhonghuang 2' (ZH2)	Fairly tippy, bright orange; fresh and moist	Tea Research Institute, Chinese Academy of Agricultural Sciences	Jinyun, Zhejiang
C. sinensis L. 'Zhonghuang 1' (ZH1)	Light green with gold edges	Tea Research Institute, Chinese Academy of Agricultural Sciences	Tiantai, Zhejiang
C. sinensis L. 'Yulu 1' (YL1)	Tippy; dark green	Tea Research Institute, Enshi Academy of Agricultural Sciences	Enshi, Hubei
C. sinensis L. 'Yuexiangzao' (YXZ)	Dark green with little jade green	Tea Research Institute, Shaoxing Academy of Agricultural Sciences	Shaoxing, Zhejiang
C. sinensis L. 'Yixuan 1' (YX1)	Tippy; dark green	Tea Research Institute, Chinese Academy of Agricultural Sciences	Hangzhou,Zhejiang
C. sinensis L. 'TRI19' (TRI19)	Dark green with a little yellow	Tea Research Institute, Chinese Academy of Agricultural Sciences	Hangzhou, Zhejiang
C. sinensis L. 'Suyuhuang' (SYH)	Slightly tippy; light green	Wuxi Tea Cultivars Research Institute	Wuxi, jiangsu
C. sinensis L. 'Shancha 1' (SC1)	Tippy; light green	Ankang Hanshuiyun Tea Co., Ltd.	Ankang, Shaanxi
C. sinensis L. 'Niaowang 106' (NW106)	Slightly tippy; dark green	Tea Research Institute, Guizhou Academy of Agricultural Sciences	Guiding, Guizhou
C. sinensis L. 'Muhe 201' (MH201)	Green with slightly gold edges	Dongyang Agriculture Technology Extension Center	Dongyang, Zhejiang
C. sinensis L. 'Laoshan 3' (LS3)	Slightly tippy; slightly dark green	Qingdao Wanlijiang Tea Co., Ltd.	Qingdao, Shandong
C. sinensis L. 'Lanlixiang' (LLX)	Fairly tippy; green	Anqing Tea Trade Associations	Anqing, Anhui
C. sinensis L. 'Gounao 02' (GN02)	Dark green with a little yellow	Suichuan Gougunao Tea Factory	Suichuan, Jiangxi
C. sinensis L. 'Echa 12' (EC12)	Tippy; green	Tea Research Institute, Hubei Academy of Agricultural Sciences	Wuhan, Hubei
C. sinensis L. 'Echa 11' (EC11)	Slightly tippy; dark green	Tea Research Institute, Hubei Academy of Agricultural Sciences	Wuhan, Hubei
C. sinensis L. 'Chanong 98' (CN98)	Dark green	Anhui Agricultural University	Hefei, Anhui
C. sinensis L. 'Caoxi 1' (CX1)	Tippy; dark green	Huangshan Xieyuda Tea Co., Ltd.	Huangshan, Anhui
C. sinensis L. 'Baiye 1' (BY1)	Green with gold edges	Agricultural Bureau of Anji County	Anji, Zhejiang
C. sinensis L. 'Fuding Dabaicha' (FD)	Tippy; green	Tea Research Institute, Fujian Academy of Agricultural Sciences	Fuding, Fujian

Supplementary Table 2. Odor detection threshold and characteristics of important volatile components.

No.	Component	Odor characteristic	Odor detection threshold (μg L^{-1})
1	Dimethyl sulfide	Sulfurous scent	1.1
2	Isovaleraldehyde	Malty fragrance	1.2
3	2-Methylbutyraldehyde	Coffee-cocoa scent	4.4
4	Toluene	Aromatic	1550
5	Hexaldehyde	Grass odor, fatty scent	10
6	p-Xylene	Aromatic	490
7	Styrene	Aromatic	65
8	Heptanal	Grass odor, fresh fruity flavor	3
9	(E)-2-Heptenal	Grass odor	0.8
10	Benzaldehyde	Almond and nutty scent	41.7
11	(2Z)-2-Octene-1-ol	Clean and refreshing	40
12	Octanal	Fresh fruity flavor	6.9
13	Limonene	Lemon flavor	10
14	Hyacinthin	Floral flavor	6.3
15	Linalool	Floral and fruity flavor	0.6
16	Nonanal	Citrus and soapy scent	8
17	Phenethyl alcohol	Rose scent	86
18	(E)-2-Nonenal	Clean and refreshing, fatty scent	0.4
19	α-Terpineol	Clove scent	250
20	Methyl salicylate	Holly scent	40
21	Capraldehyde	Grass odor, floral flavor	0.1
22	Indole	Camphor scent	40
23	Caproicacidhexneylester	Grass odor, fruity flavor	10
24	β-Ionone	Floral flavor like violet	0.2
25	Nonanal	Rose scent	3.2



Supplementary Figure 1. OPLS-DA score plot (A) derived from the volatile component contents of the green tea produced from the various tea cultivars.

Supplementary Table 3. Components with VIP values of more than 1, as determined by OPLS-DA.

No.	Aroma component	VIP
1	Linalool	1.71
2	Limonene	1.70
3	3-Carene	1.65
4	Caproicacidhexneylester	1.57
5	(E)-2-Nonenal	1.51
6	Geraniol	1.46
7	Hexaldehyde	1.43
8	(E)-β-Ocimene	1.42
9	(Z)-3-Cis-3-hexenyl isovalerate	1.41
10	Citral	1.41
11	Capraldehyde	1.40
12	Cis-linalool oxide	1.39
13	Methyl salicylate	1.39
14	Nonanal	1.35
15	α-Terpineol	1.34
16	(Z,Z)-3-Hexenoicacid-3-hexenylester,	1.30
17	β-Cyclocitral	1.21
18	Safranal	1.15
19	Octanal	1.12
20	Indole	1.10
21	Heptanal	1.08
22	(2Z)-2-Octene-1-ol	1.06
23	Geranylacetone	1.03