horticulturae

MDPI

Article

Comparison of Aroma Trait of the White-Fleshed Peach 'Hu Jing Mi Lu' and the Yellow-Fleshed Peach 'Jin Yuan' Based on Odor Activity Value and Odor Characteristics

Wenjing Liu [1], Yuanyuan Zhang [2], Ruijuan Ma [2] and Mingliang Yu [1,2,*]

[1] School of Food and Biological Engineering, Jiangsu University, Zhenjiang 212013, China; 2221918054@stmail.ujs.edu.cn
[2] Institute of Pomology, Jiangsu Academy of Agricultural Sciences/Jiangsu Key Laboratory for Horticultural Crop Genetic Improvement, Nanjing 210014, China; 20190021@jaas.ac.cn (Y.Z.); marj311@163.com (R.M.)
* Correspondence: mly1008@aliyun.com

Abstract: Peach flesh colors and aromas impact greatly on consumer behaviors and these two traits are closely associated in white- and yellow-fleshed peaches. However, current understanding of their aromas is rather limited and confined to the concentration differences of some volatiles. Therefore, this study aims to compare the overall aromas of the white-fleshed peach 'Hu Jing Mi Lu' (HJML) and yellow-fleshed peach 'Jin Yuan' (JY), two fresh cultivars with intense aromas and industrial influence by applications such as HS-SPME/GC-MS analysis, odor activity value evaluations, and odor note analysis. The significant contributions of 26 odor-active compounds to their aromas were revealed. Among which, 15 compounds showed no concentration differences and contributed to the fruity, floral, sweet, etc., odors in both HJML and JY; (E)-2-nonenal, 1-pentanol, and styrene showed significantly higher concentrations in HJML and conveyed much stronger fusel-like and balsamic odors; likewise, (Z)-3-hexenyl acetate, octanal, nonanal, and 3,5-octadien-2-one showed significantly higher concentrations in JY and conveyed much stronger banana, citrus-like, and honey odors; besides, benzyl alcohol, 1-heptanol, 1-octen-3-ol, and 3-octanone with woody, earthy, mushroom, and lavender odors were exclusively detected in HJML. Overall, apart from the common and stronger specific odors in either the white- or yellow-fleshed peach cultivar, the white-fleshed peach was endowed with a unique aroma.

Keywords: flesh colors; peach; aromas; HS-SPME/GC-MS; odor activity value

check for updates

Citation: Liu, W.; Zhang, Y.; Ma, R.; Yu, M. Comparison of Aroma Trait of the White-Fleshed Peach 'Hu Jing Mi Lu' and the Yellow-Fleshed Peach 'Jin Yuan' Based on Odor Activity Value and Odor Characteristics. *Horticulturae* **2022**, *8*, 245. https://doi.org/10.3390/horticulturae8030245

Academic Editor: Isabel Lara

Received: 2 March 2022
Accepted: 10 March 2022
Published: 14 March 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Peach (*Prunus persica* L. Batsch) spread from its origin in China to all temperate and subtropical climates within the Asian continent about 3000 years ago [1]. Subsequently, it was widely grown around the world for the attractive colors, pleasant aromas, and high nutrition values of the fruit. Peach germplasm resources are abundant in China, and three National Fruit Germplasm Repository (Zhengzhou, Beijing, and Nanjing, China) have been established, among which the National Peach Germplasm Repository in Nanjing bred many peach cultivars with high research value [2].

Peach fruit quality properties determine consumer acceptance and commodity value, and flesh color is a crucial component [3]. The different flesh colors are the results of the comprehensive presentation of carotenoids, anthocyanins, chlorophylls, flavonoids, and other compounds [4,5]. Among the above compounds, carotenoid accumulation (including biosynthesis and degradation pathways) determines the color differences between yellow- and white-fleshed peach genotypes and previous reports suggested that the total carotenoid content was much higher in yellow-fleshed fruit [6–9]. White- and yellow-fleshed peach are widely available as fresh fruit to consumers, and yellow-fleshed peach is also used for

canned goods. Generally speaking, compared with white-fleshed peach, yellow-fleshed peach is easier to attract the attention of customers and improve their purchase desire [10].

Since fruit flesh colors act as the main factors that influence customer behaviors, meanwhile aroma also determines whether customers will purchase again [11], investigations targeting the comparisons of aroma quality of fruits with distinct flesh colors are highly desirable to enlarge our global and basic knowledge of important fruit germplasm. However, currently, limited research has reported the differences of volatile compounds between white- and yellow-fleshed peach. Differences in concentrations of volatiles changes between white- and yellow-fleshed peaches during storage by stir bar sorptive extraction (SBSE) and GC-MS technology have been reported, and the influence of increasing the time of cold storage was particularly evident on both cultivars for lactones, whereas it was less marked for C13 norisoprenoids and limited to the white-fleshed cultivar [12]. Zhu et al. [13] analyzed the volatile changes in relative content between white-fleshed nectarine CN9 and its yellow-fleshed mutants by GC-MS during ripening and found that the specific volatile compounds of CN9 are mainly phenols and terpenes, and the specific volatiles of its mutants are mainly alcohols. It is observed that the above research presented the differences in the groups and relative contents of volatile compounds.

So far, over 100 aroma-related volatile compounds have been identified in peach fruit, including alcohol, aldehyde, ester, lactone, terpene, and other volatile compounds [14–16]. Each volatile compound has its own odor notes, and their different combinations contribute to the unique flavor of the fruit. Overall, ester volatile compounds such as hexyl acetate and (Z)-3-hexenyl acetate contribute to fruity odor notes [17], and γ-decalactone is considered among the most important volatile compounds of peach fruit to give the aroma of peach-like odor notes [18], and the concentrations of ester and lactone volatiles increase with fruit ripening [19]. Terpene volatile compounds contribute to sweet and floral notes, in which linalool and β-ionone are considered the main aroma compounds in peach [20]. Aldehyde and alcohol volatiles which emit grass notes are the main aroma compounds in immature fruits.

In the evaluations of the odor characteristics, odor activity value (OAV) is an important concept to measure the contributions of volatile compounds to the aroma [21]. However, previous research comparing the aromas of peaches during ripening and storage has mainly focused on the concentration changes of some volatile compounds [22–25]. For example, Leng et al. [25] analyzed the content changes of volatile compounds of 'Yingshuanghong' that were packaged with different preservation methods during storage by HS-GC-IMS with PCA, and only showed the higher OAVs of hexanal and (E)-2-hexenal in peaches, while other volatiles were not mentioned of the OAVs. Although 21 key odorants in the peach volatile composition with OAVs higher than 1 were identified, Eduardo et al. [21] did not analyze the differences of aroma between six peaches and three nectarines. Previous studies that compared aromatic differences between peach cultivars based on both OAVs and odor characteristics of volatiles were very limited, which is particularly important in the comprehensive investigations of the contributions of odor-active compounds (OAV > 1) to the aroma of peach fruit.

Among the white-fleshed peach cultivars, 'Hu Jing Mi Lu' (HJML) is jade white, dense, soft, juicy, the taste is fresh and sweet, and the aroma is rich [26]. Among the yellow-fleshed peach cultivars, 'Jin Yuan' is the main representative of melting types and the main fresh yellow-fleshed peach cultivars in the south of the Yangtze River in China [27]. As melting peach fruits, HJML and JY are largely planted in China with great significance in the peach industry and serve as ideal peach fruit materials to explore the aromatic qualities between the white-fleshed peach and the yellow-fleshed peach fruit.

In the present study, the white-fleshed peach cultivar 'Hu Jing Mi Lu' and the yellow-fleshed peach cultivar 'Jin Yuan' in the National Peach Germplasm Repository in Nanjing were investigated for their different aroma characteristics. We identified the odor-active compounds in HJML and JY by calculating the OAV of each volatile compound and analyzed the odor characteristics and aroma differences. These results will provide the

basis for identifying the flavor qualities of white- and yellow-fleshed peaches, which in turn link the important color and aroma traits and provide directions for further explorations on the regulations and modifications of these quality parameters in fruit.

2. Materials and Methods

2.1. Fruit Materials

'Hu Jing Mi Lu' (*Prunus persica* L. Batsch) and 'Jin Yuan' (*Prunus persica* L. Batsch) mature fruits were picked from the National Peach Germplasm Repository in Nanjing, Jiangsu Province, China, in 2020 and transported carefully to the laboratory within half an hour on the harvest day. Eighteen fruits in each cultivar with the same size and shape were selected, and six fruits in each biological replicate. The mesocarp was cut into pieces, frozen immediately in liquid nitrogen, ground into powder, and stored at −80 °C for use.

2.2. HS-SPME Extraction of Volatiles

Volatile compounds were extracted using headspace solid-phase microextraction (HS-SPME) [19]. Firstly, a total of 5 g frozen sample powder was weighed in the vial, and the vial was placed in a water bath of 30 °C for 2 min. Afterwards, 4 mL of saturated NaCl solution and 10 μL of 2-octanol (0.0819 μg μL^{-1}) as the internal standard were added into the vial and the mixture was homogenized. The volatiles were extracted by HS-SPME with a 65 μm polydimethylsiloxane-divinylbenzene fiber. Initially, vials were preincubated at 40 °C for 30 min under continuous agitation (500 rpm); then, volatiles were extracted for 30 min at the same temperature and agitation speed.

2.3. GC-MS Analysis of Volatiles

Volatile compounds were analyzed using a 5975C mass spectrometer (Agilent Technologies, Santa Clara, CA, USA) coupled to a 7890A GC chromatograph, which was equipped with a DB-wax column (30 m × 0.32 mm × 0.25 μm; J&W Scientific, Folsom, CA, USA), with helium as the carrier gas at a constant flow of 1.6 mL min^{-1}. After that, the fiber (length 1 cm) was desorbed in the GC injection port for 5 min in a splitless mode. The GC device was programmed at an initial temperature of 34 °C for 2 min, with a ramp of 2 °C min^{-1} up to 60 °C, then with a ramp of 5 °C min^{-1} up to 220 °C, and held for 2 min. The injection port, interface, and MS source temperatures were 250 °C, 260 °C, and 230 °C, respectively. Mass spectra were recorded in electron impact (EI) ionization mode at 70 eV, and the scanning speed was seven scans per second.

2.4. Volatiles Identification and Concentrations Calculation

Volatile compounds were identified by comparison of electron ionization mass spectra and retention time data with the data from the NIST/EPA/NIH mass spectral library (NIST-08) and the lactone volatile compounds were determined by standard compounds. The relative contents of volatile compounds were calculated using the peak area of the internal standard—2-octanol as a reference.

2.5. Calculation of the Odor Activity Values (OAVs) of Volatile Compounds

The odor activity value (OAV) of one volatile compound was the ratio of its concentrations to its odor threshold [28], and the threshold was obtained through the literature [29]. The volatile compounds with OAV > 1 were named odor-active compounds and further analyzed.

2.6. Statistical Analysis

A complete randomized design was used in the experiments. The table was created by Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA). OriginPro 2018C (OriginLab Corporation, Northampton, MA, USA) was used to create the column chart. IBM SPSS Statistics 25 (IBM Corporation, Chicago, IL, USA) was used to calculate the standard

errors (SE) and analyze the significant differences, and comparisons were analyzed using independent samples T-test at the 5% level ($p \leq 0.05$).

3. Results

3.1. Chemical Groups of Volatile Compounds in the White- and Yellow-Fleshed Peach

GC-MS analysis showed a total of 102 volatile compounds were detected in the fruit of these two cultivars, including 16 ester and lactone volatiles, 35 aldehyde and alcohol volatiles, 15 terpene volatiles, and 36 other volatiles (Figure 1). A sum of 83 volatiles were present in the fruit of 'Hu Jing Mi Lu' (HJML) and 80 volatiles in 'Jin Yuan' (JY).

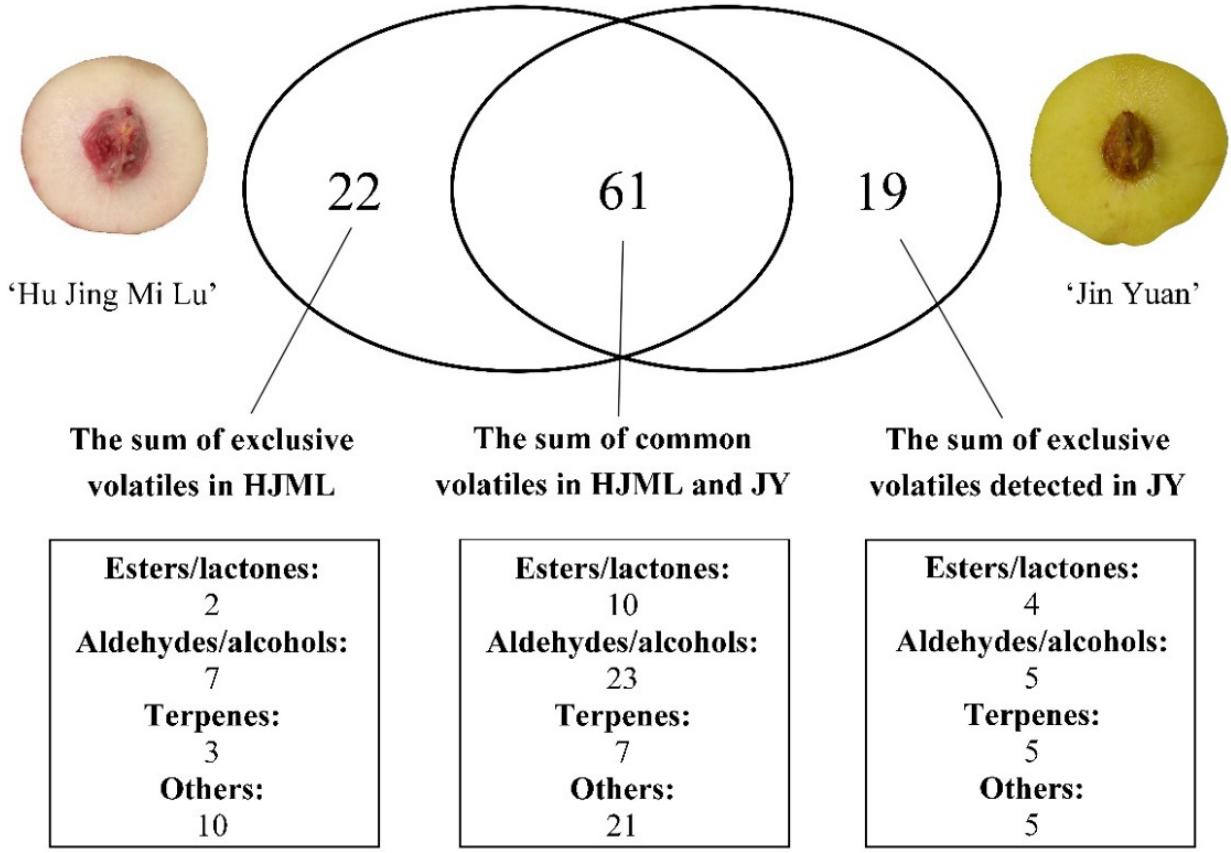

Figure 1. The sum of exclusive and common volatile compounds in 'Hu Jing Mi Lu' and 'Jin Yuan' as shown in the Venn diagrams. The number of volatile compounds in esters/lactones, aldehydes/alcohols, terpenes, and other groups were indicated.

Esters and lactones constituted the important groups in the two cultivars due to their contributions to the fruity odor. The common lactone volatiles detected in both two cultivars included γ-hexalactone, γ-decalactone, δ-deca-2,4-dienolactone, δ-decalactone, and jasmine lactone, a total of 5 compounds, and the common ester volatiles present in both two cultivars were pentyl acetate, prenyl acetate, hexyl acetate, (Z)-3-hexenyl acetate, and 2-ethyl-3-hydroxyhexyl-2-methylpropanoate, a total of 5 compounds. Apart from the common ester and lactone volatile compounds in both cultivars, exclusive volatile compounds were observed. A total of 2 compounds including (Z)-2-pentenyl acetate and dibutyl phthalate were exclusively detected in HJML, and 4 compounds including γ-octalactone, (Z)-2-hexenyl acetate, decyl acetate, and methyl hexadecanoate were exclusively detected in JY.

Aldehydes and alcohols are important to the overall green odor notes of many peach cultivars, and HJML and JY are no exception. A total of 16 common aldehyde volatile

compounds were detected in HJML and JY, which were heptanal, octanal, nonanal, decanal, benzaldehyde, p-tolualdehyde, 3-hexenal, (E)-2-hexenal, 2-heptenal, (E)-2-octenal, (E,E)-2,4-heptadienal, (E)-2-nonenal, (E,E)-2,6-nonadienal, (E,E)-2,4-nonadienal, (E,E)-2,4-decadienal, and cinnamaldehyde. There were 2 aldehyde compounds, hexanal,2-ethyl- and 5-oxymethylfurfurole, exclusively detected in HJML. There were 7 common alcohol volatiles detected in both cultivars, including 1-pentanol, 1-hexanol, 1-heptanol, 2-ethylhexanol, (Z)-3-hexen-1-ol, (Z)-2-hexen-1-ol, and (E)-2-hepten-1-ol. In addition, a total of 6 alcohol compounds such as 5-methyl-1-heptanol, 3-octanol, benzyl alcohol, (E)-2-octen-1-ol, (Z)-3-nonen-1-ol, and (E)-2-nonen-1-ol were exclusively detected in HJML, and 4 alcohol compounds such as cyclooctyl alcohol, 1-undecanol, 5-hepten-2-ol,6-methyl-, and n-heptadecanol-1 were exclusively detected in JY.

A total of 15 terpene volatile compounds were detected in HJML and JY, among which levomenthol, limonene, 1-octen-3-ol, linalool, α-terpineol, geranyl acetone, and β-ionone were common terpene volatiles in the two cultivars. Longifolene, citral and dihydro-β-ionone, a total of 3 terpene compounds, were exclusively detected in HJML, and camphore, β-myrcene, hotrienol, campholenal, and pinocarvone, a total of 5 terpene compounds, were exclusively detected in JY.

In addition to ester, lactone, aldehyde, alcohol, and terpene volatile compounds, there were volatiles in other groups. Furan and ether volatile compounds were exclusively present in HJML, comprising linalool oxide and 2-pentylfuran in the furan group and theaspirane in the ether group. There were 21 common volatile compounds detected in two cultivars, including benzoic acid, methylcyclohexane, tetradecane, styrene, 1-heptene, azulene, o-xylene, p-xylene, β-cymene, 1-methylnaphthalene, 1-octen-3-one, 6-methyl-5-heptene-2-one, 3,5-octadien-2-one, 3-octanone, 2-octanone, 2,5-octanedione, acetophenone, 1,4-benzenedicarboxaldehyde, 2-methylnaphthalene, benzothiazole, and oxime-,methoxy-phenyl-_. There were 7 volatiles including octanoic acid, tridecanoic acid, dodecanoic acid, nonadecane, cyclohexene,3-propyl-, 1,3-di-tert-butylbenzene, and 5thenone,1-(4-ethylphenyl)- were exclusively detected in HJML, and a total of 5 volatiles including 17-octadecynoic acid, hexanoic acid,2-ethyl-, cyclohexane,ethyl-, 3-Buten-2-one,4-phenyl-, and 9H-fluorene,9-methyl- were exclusively detected in JY.

In summary, a total of 61 common volatile compounds were detected in both cultivars; meanwhile, 22 exclusive volatile compounds were detected in HJML, and 19 exclusive volatile compounds were detected in JY.

3.2. Comparison of the Odor-Active Compounds in the White- and Yellow-Fleshed Peach

Not all volatile compounds make a considerable contribution to peach aroma, and only those with OAV above 1 are considered odor important. Among all detected volatile compounds in each cultivar, 26 volatile compounds were odor important in HJML with OAVs above 1 and 22 volatile compounds were odor important in JY (Figure 2).

Among the common ester volatiles in two cultivars, the odor activity values of only two esters—hexyl acetate and (Z)-3-hexenyl acetate—were above 1, indicating their important contributions to the fruity and floral notes of peach (Table 1). (Z)-2-Hexenyl acetate and decyl acetate, with fruity, floral, and orange-rose notes, were exclusively detected in JY, but their contributions to fruit aroma were limited due to their high odor thresholds (320 and 225 $\mu g \cdot kg^{-1}$, respectively) and low concentrations. γ-Decalactone has a pleasant, fruity, and peach-like odor and a very low odor threshold (1 $\mu g \cdot kg^{-1}$), and the OAVs of it in HJML and JY were 17.38 and 19.94, respectively (Table 1), making it the common odor-important lactone in both cultivars. For other common lactone volatiles, such as jasmine lactone and γ-hexalactone, which have coconut, jasmine, woody, balsamic, and herbaceous notes besides fruity and peach-like odor, their odor thresholds were, respectively, 2000 and 1600 $\mu g \cdot kg^{-1}$, and their OAVs in both cultivars were below 1. Therefore, among the esters and lactones detected in two cultivars, only hexyl acetate, (Z)-3-hexenyl acetate, and γ-decalactone contributed significantly to the fruity odor of peach fruits.

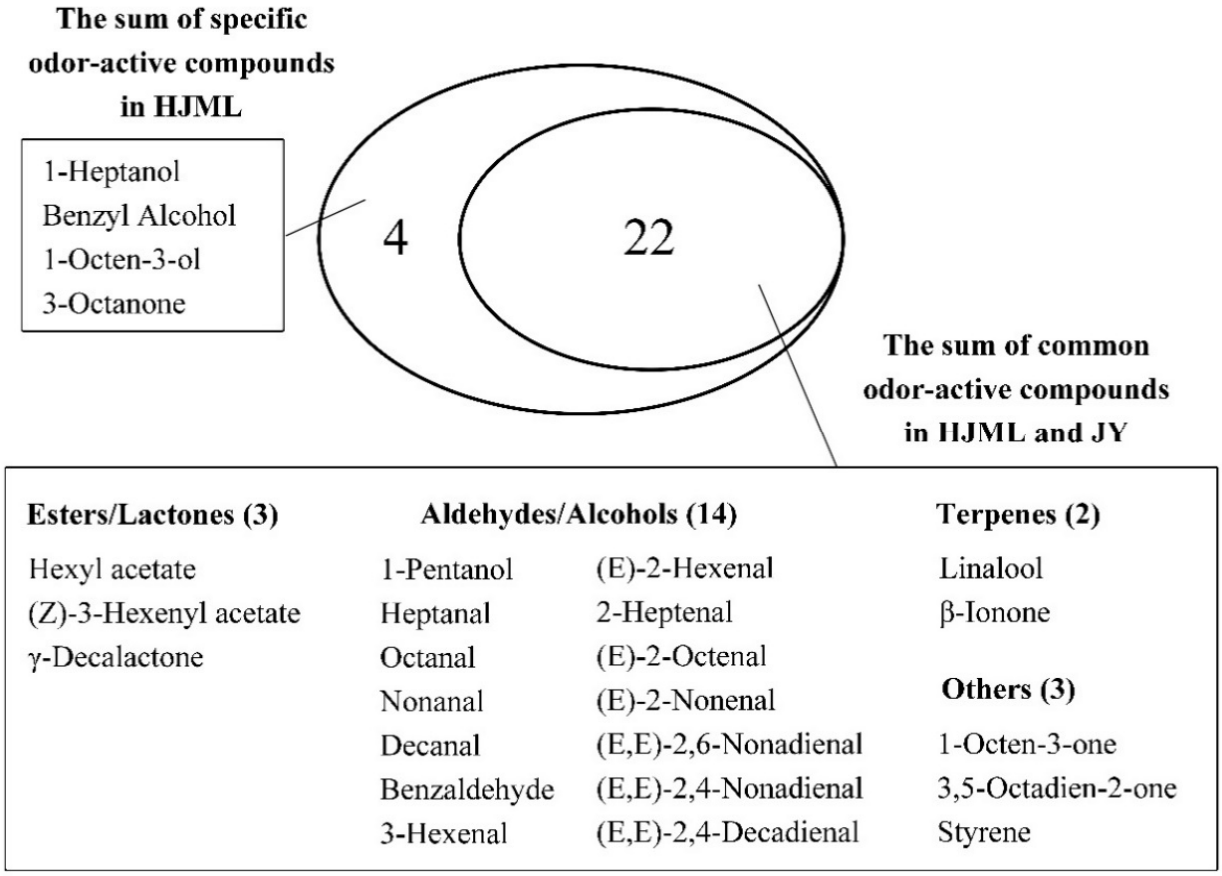

Figure 2. Specific and common odor-active compounds in 'Hu Jing Mi Lu' and 'Jin Yuan' as shown in the Venn diagrams. The common odor-active compounds grouped into esters/lactones, aldehydes/alcohols, terpenes, and others were listed.

In the two cultivars, OAVs of half of the detected aldehyde and alcohol volatiles were higher than 1, which signified that these volatiles gave the fruit a generally sweet, fatty, green, fruity, and citrus-like odor (Table 1). The common odor-important aldehyde and alcohol volatile compounds included 1-pentanol, heptanal, octanal, nonanal, decanal, benzaldehyde, 3-hexenal, (E)-2-hexenal, 2-heptenal, (E)-2-octenal, (E)-2-nonenal, (E,E)-2,6-nonadienal, (E,E)-2,4-nonadienal, and (E,E)-2,4-decadienal, and benzyl alcohol and 1-heptonal were the specific odor-important alcohol volatile compounds in HJML with OAVs of 2.02 and 1.36, respectively, while the OAV of 1-heptanol was below 1 and benzyl alcohol was not detected in JY. (E)-2-Nonenal exhibited the highest odor activity values in all detected volatiles in HJML, being up to 210.37, while only 80.16 in JY. The OAV of decanal reached 75.52, ranking fourth in all detected volatiles in HJML and about 1.86 times the value of that in JY. Some aldehydes and alcohols have other odor notes except for green odor, such as 1-pentanol with OAVs of 4.48 and 2.93, respectively, in HJML and JY, which has a characteristic fusel-like sweet and pleasant odor that was very distinct, and (E,E)-2,4-decadienal which has an oily and chicken fat odor with OAVs up to 19.06 and 26.25, respectively, in HJML and JY.

Two terpene volatiles—linalool and β-ionone—were odor important in both cultivars with the floral odor notes (Table 1). The higher OAVs of linalool, that being up to 104.68 in JY and higher OAVs of β-ionone, that being up to 119.20 in HJML, indicated their distinct contributions to the aroma of the respective cultivar. Moreover, the odor activity values of 1-octen-3-ol, the specific odor-important compounds in HJML, with earthy, herbaceous, and rose odor in HJML (1.84) were higher than those in JY (0.56). Although levomenthol, limonene, α-terpineol, and geranyl acetone have unique flavors, such as peppermint-

like, lemon-like, turpentine-like, and lilac odor, which would bring different olfactory experiences to peach fruit, the OAVs of them were below 1. Above all, linalool, β-ionone, and 1-octen-3-ol made significant contributions to the aromatic quality of HJML and JY fruit.

In addition, there are other volatile compounds that are important to the aroma of HJML and JY. 1-octen-3-one, which confers a mushroom odor, was of the highest odor activity values (130.21) in all detected volatiles in JY. 3-Octanone, which was the specific odor-important compound in HJML, has a fruity and lavender odor with an OAV of 1.07 while being below 1 in JY. Together with 1-heptanol, 1-octen-3-ol, and benzyl alcohol, 3-octenone contributed to the distinct aroma of HJML and JY. As a common ketene volatile compound, 3,5-octadien-2-one has an herbaceous odor note, with OAVs of 16.50 and 20.44, respectively, in HJML and JY. Moreover, the OAVs of styrene were, respectively, 2.28 and 1.11 in HJML and JY, which give a sweet, balsamic, and floral odor.

Overall, 22 common odor-active compounds were identified in two cultivars and 4 specific odor-active compounds were identified in HJML, among which benzyl alcohol was not detected in JY, and 1-heptanol, 1-octen-3-ol, and 3-octanone were detected in JY but their OAVs were all below 1.

Table 1. Odor description, odor threshold in water and odor-active compounds (OAV > 1) in 'Hu Jing Mi Lu' and 'Jin Yuan'.

Classification	Volatile Compounds	Odor Description [1]	Concentrations (μg/kg·FW)		Odor Threshold in Water (μg·kg^{-1}) [1]	OAV	
			HJML	JY		HJML	JY
Esters and Lactones	Hexyl acetate	Fruity, apple, cherry, pear, floral	13.23 ± 1.61 a	21.73 ± 2.72 a	2	6.61	10.86
	(Z)-3-Hexenyl Acetate	Green, fruity, floral, banana	192.44 ± 22.83 b	318.83 ± 11.25 a	7.8	24.67	40.88
	γ-Decalactone	Fruity, peach-like	17.39 ± 2.71 a	16.94 ± 1.84 a	1	17.38	16.94
Alcohols and Aldehydes	1-Pentanol	Fusel-like	7.17 ± 0.77 a	4.68 ± 0.45 b	1.6	4.48	2.93
	1-Heptanol	Fragrant, woody, fatty	4.09 ± 0.24 a	2.08 ± 0.03 b	3	1.36	<1
	Benzyl Alcohol	Fruity	2.43 ± 0.44	-	1.2	2.02	-
	Heptanal	Fatty	6.99 ± 0.92 a	6.33 ± 0.85 a	3	2.33	2.11
	Octanal	Fatty, citrus, honey	3.35 ± 0.14 b	5.15 ± 0.37 a	1.4	2.39	3.68
	Nonanal	Fatty, citrus-like	7.79 ± 0.49 b	10.41 ± 0.61 a	1	7.79	10.41
	Decanal	Sweet, waxy, floral, Citrus, fatty	7.55 ± 0.85 a	4.06 ± 0.23 a	0.1	75.52	40.60
	Benzaldehyde	Almond, cherry, nutty	155.76 ± 31.23 a	272.93 ± 64.39 a	100	1.56	2.73
	3-Hexenal	Green, fruity, apple-like	9.28 ± 1.52 a	6.07 ± 0.09 a	0.25	37.10	24.27
	(E)-2-Hexenal	Sweet, almond, fruity Green, apple, plum	594.95 ± 60.89 a	671.70 ± 33.84 a	30	19.83	22.39
	2-Heptenal	Fatty	22.21 ± 2.07 a	24.88 ± 3.72 a	13	1.71	1.91
	(E)-2-Octenal	Green	13.59 ± 0.75 a	14.93 ± 1.34 a	3	4.53	4.98
	(E)-2-Nonenal	Fatty	21.04 ± 4.48 a	8.02 ± 0.57 b	0.1	210.37	80.16
	(E,E)-2,6-Nonadienal	Green, vegetable	7.40 ± 1.51 a	3.01 ± 0.20 a	0.09	82.19	33.45
	(E,E)-2,4-Nonadienal	Fatty, floral	3.35 ± 0.84 a	3.52 ± 0.34 a	0.05	66.97	70.47
	(E,E)-2,4-Decadienal	Oily, chicken fat	1.33 ± 0.12 a	1.84 ± 0.19 a	0.07	19.06	26.25
Terpenes	1-Octen-3-ol	Sweet, earthy, herbaceous, rose, mushroom	25.76 ± 3.85 a	7.87 ± 0.64 b	14	1.84	<1
	Linalool	Floral	464.28 ± 143.93 a	418.74 ± 45.02 a	4	116.07	104.68
	β-Ionone	Floral	0.83 ± 0.13 a	0.67 ± 0.12 a	0.007	119.20	95.52
Others	1-Octen-3-one	Mushroom	4.72 ± 0.20 a	6.51 ± 1.08 a	0.05	94.40	130.21
	3,5-Octadien-2-one	Herbaceous	2.48 ± 0.06 b	3.07 ± 0.00 a	0.15	16.50	20.44
	Styrene	Sweet, balsamic, floral	8.22 ± 0.82 a	4.01 ± 0.12 b	3.6	2.28	1.11
	3-Octanone	Fruity, lavender	22.46 ± 2.19 a	11.54 ± 0.23 b	21	1.07	<1

[1] Ref. [29]. Note: -, not detected. Different letters after peer data indicate significant difference ($p \leq 0.05$).

3.3. Concentrations of Odor-Active Compounds in the White- and Yellow-Fleshed Peach

The total concentrations of volatile compounds detected in HJML and JY were 2016.09 ± 182.90 μg·kg^{-1} and 2169.94 ± 133.15 μg·kg^{-1}, respectively. Based on the chemical structures, volatile compounds were classified and the relative contents were compared by major groups between two cultivars (Figure 3). The relative contents of aldehydes and alcohols were the highest in both cultivars, reaching above 50% in HJML and JY. The relative contents of esters and lactones were 18.68% in JY, being higher than those in HJML; and the relative contents of terpenes were 26.01% and 20.99% in HJML and JY, respectively. Volatiles in other groups represented relatively much smaller proportions in both cultivars.

Therefore, the contents difference of volatile compounds between two cultivars was mainly exhibited in esters, lactones, and terpenes.

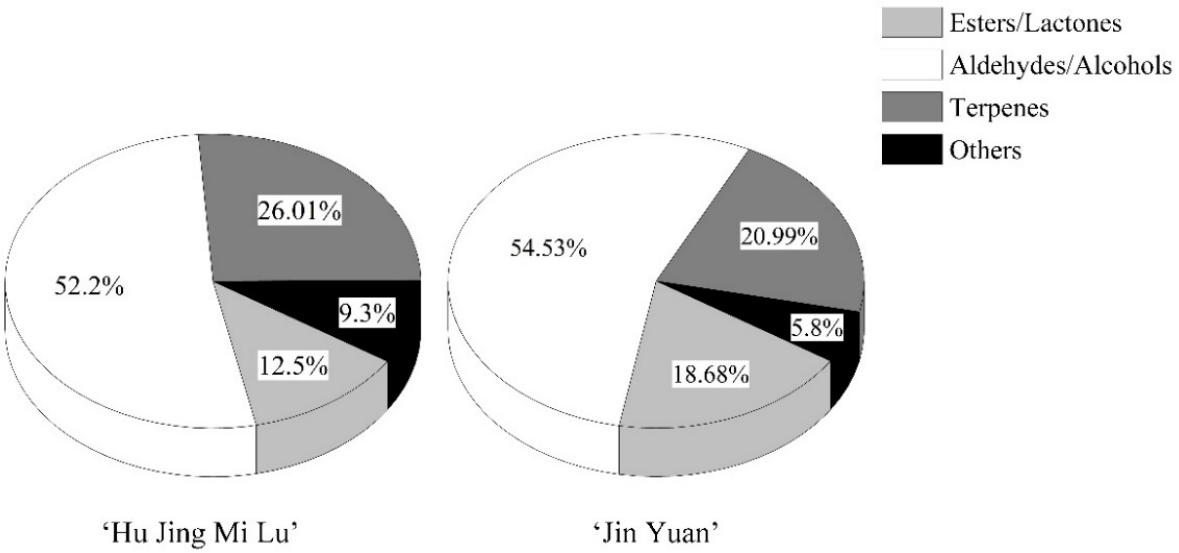

Figure 3. Contents of volatile compounds in the major groups in 'Hu Jing Mi Lu' and 'Jin Yuan'. Content percentages of volatile compounds in the major groups were shown in each cultivar.

Analysis of the OAVs showed 4 specific odor-active compounds in HJML and 22 common odor-active compounds contributed to the aroma of HJML and JY, and concentrations of some compounds differed largely between the two cultivars.

The concentration of (Z)-3-hexenyl acetate in JY was 318.83 $\mu g \cdot kg^{-1}$, which was 0.66 times significantly higher than that in HJML (Figure 4A), indicating the possibility that the related odor quality of JY could be perceived with higher intensity. Another common odor-important ester compound, hexyl acetate, showed no significant differences in the concentrations between HJML and JY (13.23 and 21.73 $\mu g \cdot kg^{-1}$, respectively) (Figure 5A). The concentrations of γ-decalactone were 17.38 and 16.94 $\mu g \cdot kg^{-1}$ in HJML and JY, showing no significant differences (Figure 5A).

The concentrations of (E)-2-hexenal were the highest of all volatiles in HJML and JY, being 594.95 $\mu g \cdot kg^{-1}$ and 670.70 $\mu g \cdot kg^{-1}$, respectively (Figure 5B). There were significant differences in concentrations of (E)-2-nonenal between HJML and JY, which were 21.04 $\mu g \cdot kg^{-1}$ and 8.02 $\mu g \cdot kg^{-1}$, respectively (Figure 4B). The concentrations of octanal and nonanal in JY were 5.15 $\mu g \cdot kg^{-1}$ and 10.41 $\mu g \cdot kg^{-1}$, respectively, significantly higher than those in HJML. The concentrations of benzaldehyde, which showed no significant difference in the two cultivars, were much higher than other aldehyde volatile compounds such as heptanal, octanal, nonanal, and decanal. 1-Pentanol was the only common odor-important alcohol volatile compound with an OAV above 1 between the two cultivars, and its concentration in HJML was 7.17 $\mu g \cdot kg^{-1}$, significantly higher than that in JY. Among the common odor-important aldehyde and alcohol volatile compounds, only 1-pentanol, octanal, nonanal, and (E)-2-nonenal showed significant differences in concentration between HJML and JY (Figure 4B), while others showed no significant differences in concentration such as (E,E)-2,4-decadienal, (E,E)-2,4-nonadienal, (E,E)-2,6-nonadienal, 3-hexenal, (E)-2-octenal, (E)-2-hexenal, and 2-heptenal (Figure 5B). In addition to the above common odor-important aldehydes and alcohols, the specific odor-important compound of HJML—1-heptanol—showed significant differences in the two cultivars, being 4.09 $\mu g \cdot kg^{-1}$ in HJML and 2.08 $\mu g \cdot kg^{-1}$ in JY. Moreover, the concentration of benzyl alcohol, which was the odor-important alcohol compound of HJML but not detected in JY, was 2.43 $\mu g \cdot kg^{-1}$ in HJML (Figure 4B).

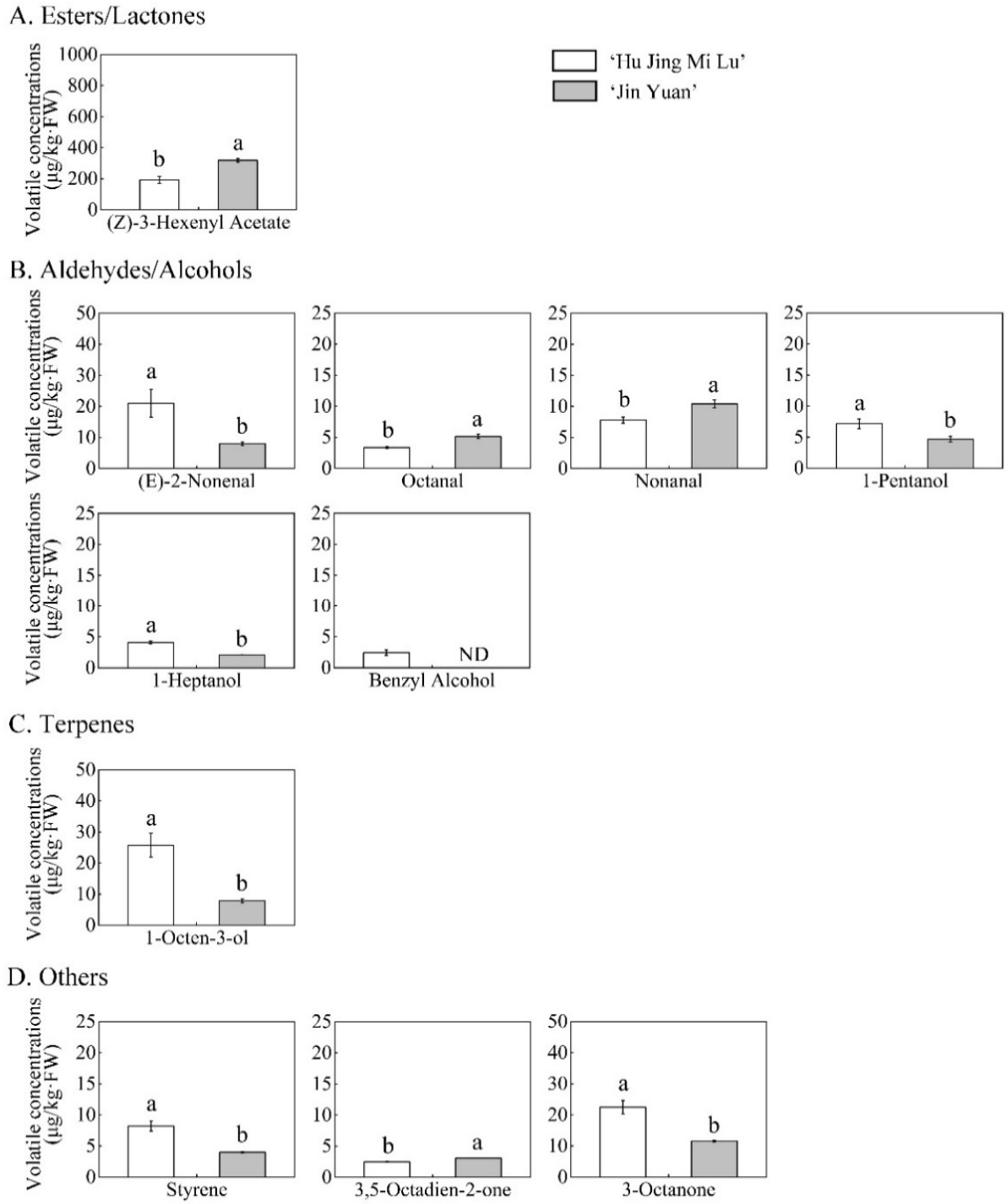

Figure 4. The concentrations of odor-active compounds in 'Hu Jing Mi Lu' and 'Jin Yuan'. (**A**) The concentrations of odor-important ester and lactone volatile compounds in HJML and JY. (**B**) The concentrations of odor-important aldehyde and alcohol volatile compounds in HJML and JY. Note: ND, not detected. (**C**) The concentrations of odor-important terpene volatile compounds in HJML and JY. (**D**) The concentrations of odor-important other volatile compounds in HJML and JY. SE values were calculated from three replicates, and comparisons were analyzed using independent samples T-test at the 5% level ($p \leq 0.05$). Different letters indicate significant difference ($p \leq 0.05$).

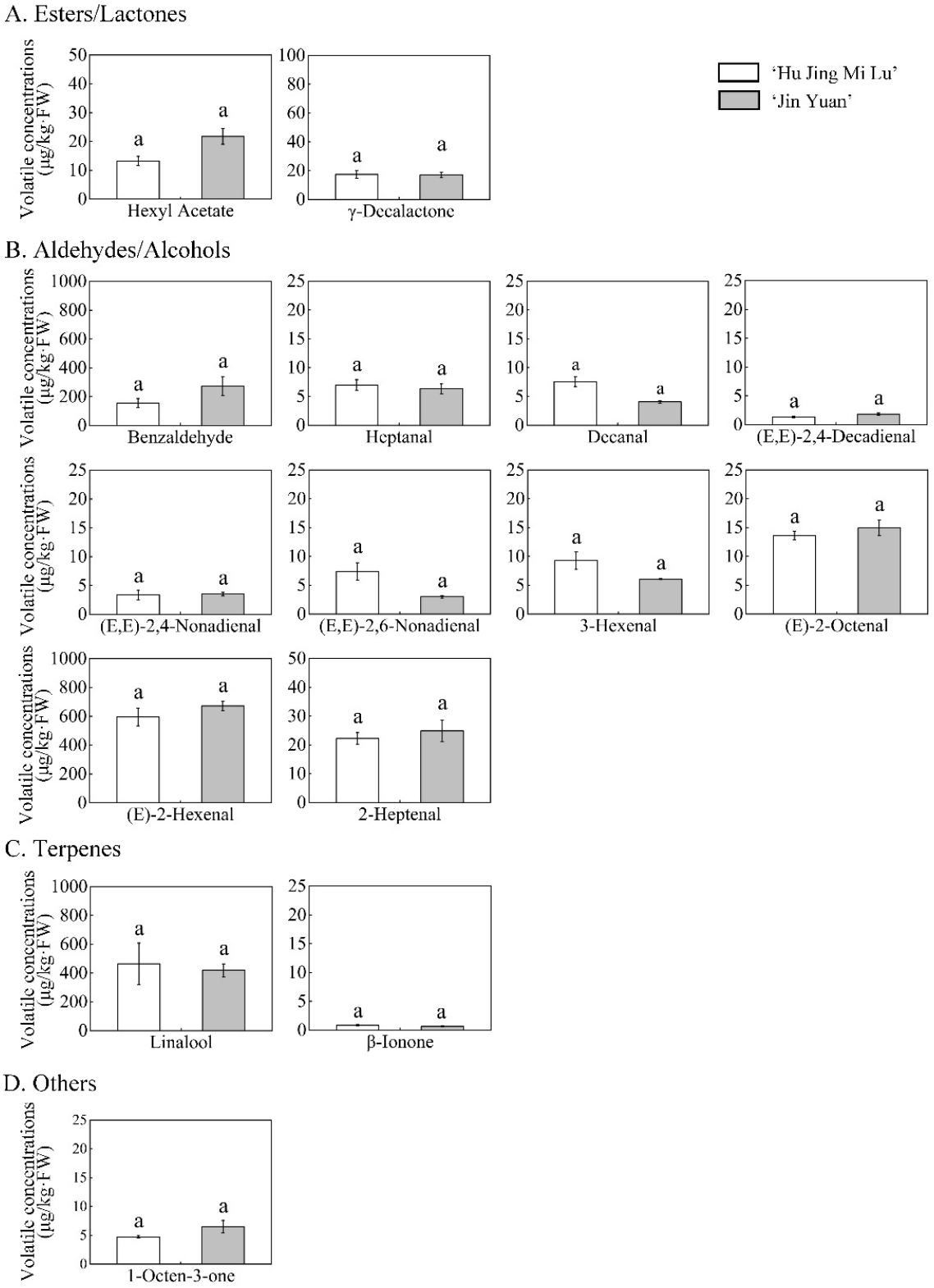

Figure 5. The concentrations of odor-active compounds in 'Hu Jing Mi Lu' and 'Jin Yuan'. (**A**) The concentrations of odor-important ester and lactone volatile compounds in HJML and JY. (**B**) The concentrations of odor-important aldehyde and alcohol volatile compounds in HJML and JY. Note: ND, not detected. (**C**) The concentrations of odor-important terpene volatile compounds in HJML and JY. (**D**) The concentrations of odor-important other volatile compounds in HJML and JY. SE values were calculated from three replicates, and comparisons were analyzed using independent samples T test at the 5% level ($p \leq 0.05$). Letter a indicate no significant difference ($p \leq 0.05$).

All the common odor-important terpene volatiles—linalool and β-ionone—showed no significant differences in the concentrations between the two cultivars (Figure 5C). The concentrations of linalool were as high as 468.28 $\mu g \cdot kg^{-1}$ in HJML and 418.74 $\mu g \cdot kg^{-1}$ in JY, while the concentrations of β-ionone were much lower, 0.83 $\mu g \cdot kg^{-1}$ in HJML and 0.67 $\mu g \cdot kg^{-1}$ in JY. However, the concentration of 1-octen-3-ol, which was the specific odor-important terpene compound of HJML while detected in both cultivars, was 25.76 $\mu g \cdot kg^{-1}$ in HJML, which was three times higher than that in JY approximately (Figure 4C). 1-Octen-3-ol was the only odor-important compound of all terpene volatiles with significantly different concentrations in the two cultivars, and it was the difference in concentration that formed the difference of terpene aroma between the two cultivars.

There were significant differences in the concentrations of other volatile compounds between the two cultivars. The concentration of styrene in HJML was as high as 8.22 $\mu g \cdot kg^{-1}$, which was twice that in JY (Figure 4D). The concentrations of 3,5-octadiene-2-one were 2.47 $\mu g \cdot kg^{-1}$ in HJML and 3.06 $\mu g \cdot kg^{-1}$ in JY, and there was a significant difference. Moreover, the concentration of the specific odor-important compound in HJML—3-octanone—was significantly different between the two cultivars, which were 22.46 $\mu g \cdot kg^{-1}$ and 11.54 $\mu g \cdot kg^{-1}$, respectively, in HJML and JY. 1-Octen-3-one showed no significant difference in concentrations between the two cultivars (Figure 5D).

In summary, there were 22 common odor-active compounds in two cultivars and 4 specific odor-active compounds in HJML that contributed considerably to the unique aromas of the two cultivars (Figure 6). Among the above 22 common odor-active compounds, 15 compounds (1 ester, 1 lactone, 10 aldehydes, 2 terpenes, and 1 other compound) showed no significant differences in the concentrations between the two cultivars and 7 compounds (1 ester, 3 aldehydes, 1 alcohol, and 2 other compounds) were significantly different in concentrations between the two cultivars. Contributing mainly to the above 15 common odor-active compounds, including hexyl acetate, γ-decalactone, benzaldehyde, heptanal, decanal, (E,E)-2,4-decadienal, (E,E)-2,4-nonadienal, (E,E)-2,4-nonadienal, 3-hexenal, (E)-2-octenal, (E)-2-hexenal, 2-heptenal, linalool, β-ionone, and 1-octen-3-one, there were common fruity, floral, sweet, fatty, green, and peach-like odor notes in both the white- and yellow-fleshed peach fruits. The fusel-like and balsamic odor quality of the three common odor-active compounds, (E)-2-nonenal, 1-pentanol, and styrene, could be perceived with higher intensity in HJML due to the higher concentrations; likewise, the banana, citrus-like, and honey odor quality of the other four common odor-active compounds, (Z)-3-hexenyl acetate, octanal, nonanal, and 3,5-octadien-2-one, could be perceived with higher intensity in JY due to the higher concentrations. Moreover, the white-fleshed peach was distinguished from the yellow-fleshed peach fruit by the unique woody, earthy, mushroom, and lavender odor notes due to the presence of 4 specific odor-active compounds in HJML including 1-heptanol, benzyl alcohol, 1-octen-3-ol, and 3-octanone.

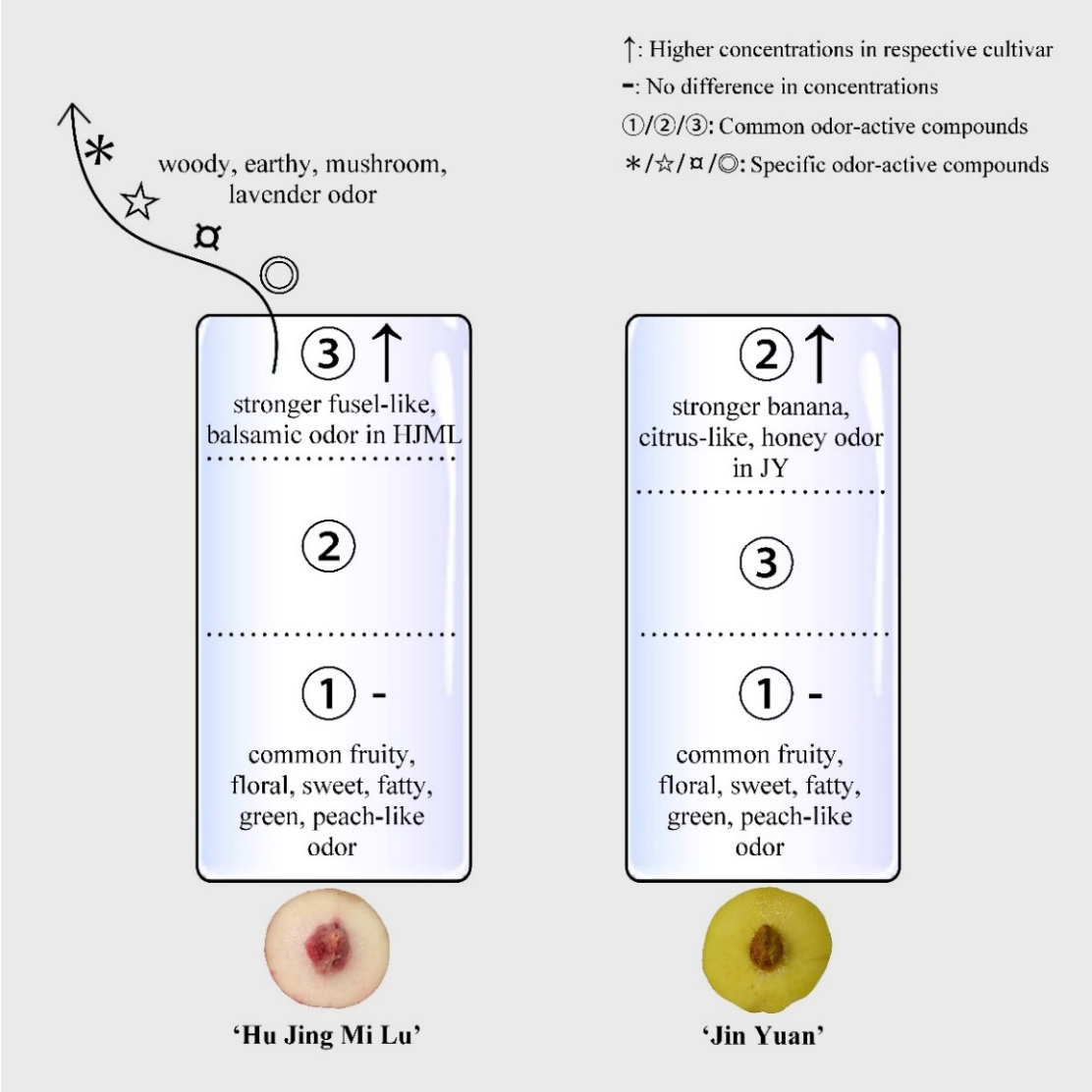

Figure 6. Odor characteristics of the white-fleshed peach 'Hu Jing Mi Lu' and yellow-fleshed peach 'Jin Yuan'. ①②③ Indicate the total 22 common odor-active volatiles in two cultivars. ② Represents (Z)-3-hexenyl acetate, octanal, nonanal and 3,5-octadien-2-one, ③ represents (E)-2-nonenal, 1-pentanol and styrene, and ① represents the remaining 15 common odor-active compounds. The specific odor-active compounds include 1-heptanol, 1-octen-3-ol, 3-octanone and benzyl alcohol.

4. Discussion

Aroma is considered an important component in the determination of peach quality. So far, more than 100 volatile aromatic compounds have been identified in peach fruits [15], which can be divided into C6 alcohols, aldehydes, esters, lactones, terpenes, and other volatiles according to the different functional groups of the compounds, and classified as green, floral, fruity, and sweet volatiles according to different odor characteristics [30]. In this study, a total of 102 volatile compounds distributed in the above-mentioned groups were identified in HJML and JY, including esters and lactones with a fruity odor, aldehydes and alcohols with a green odor, and terpenes with a floral odor, etc.

Horvat et al. [20] identified five volatile compounds in 'Cresthaven' and 'Monroe', including the green volatiles—hexanal, (E)-2-hexenal, and benzaldehyde—and the floral volatiles—linalool and γ-decalactone—as the main flavor compounds in peach fruit. Among the above volatiles, only hexanal was not detected in the mature fruits in this study, which is reasonable given that the concentrations of hexanal showed decreased accumu-

lation patterns during fruit development and ripening [5]. By comparing the changes in volatile compositions and their concentrations in 'Okubo' peach at a constant temperature during postharvest storage, Li et al. [31] found that the ratio of the concentrations of green volatiles—hexanal, (E)-2-hexenal, and benzaldehyde—to the concentrations of floral volatiles—linalool and γ-decalactone—might determine the flavor of peach, and the lower the radio was, the stronger the flavor of the peach would be. The ratio of green volatiles concentrations and floral volatiles concentrations of 'Hu Jing Mi Lu' fruits dropped to 5.77 on the second day during postharvest storage, and that was the time when the peach had the best flavor [32]. Based on the above previous studies, the ratios of contents of the green volatiles content and the floral volatiles were also calculated in this study, which were 1.56 and 2.16, respectively, in the white-fleshed peach HJML and yellow-fleshed peach JY, which illustrated that the aroma of HJML was stronger than JY and the aroma of both cultivars was more intense than that of the experiment fruits as investigated by Fan and Cui [32].

Fruits of different species or even the same species but different cultivars have different characteristics of volatile compounds, and the specific compositions and proportions of volatiles endow the fruit unique aromas [14,21]. The contribution of volatile compounds to fruit aroma is usually evaluated by the odor activity value, which is the ratio of the concentrations of volatiles to its odor threshold in water [33]. The greater the odor activity value is, the stronger the aroma [34]. Not only the richness of the aroma was different between HJML and JY as shown above but also there were distinct differences in their odor characteristics. It is precisely because of the different combinations of the odor-important compounds and the distinct contributions of each compound to the peach aroma that HJML and JY were endowed with unique odors. In this study, the volatile compounds with OAV > 1 were specified as odor-active compounds, with a total of 26 in two cultivars (Figure 2). Meanwhile, there were seven common odor-active compounds such as (Z)-3-hexenyl acetate, 1-pentanol, octanal, nonanal, (E)-2-nonenal, styrene, and 3,5-octadien-2-one and four specific odor-active compounds in HJML such as benzyl alcohol, 1-octen-3-ol, 3-octanone, and 1-heptanol with significant differences in concentrations between the two cultivars (Figure 4), and this result was validated in another yellow-fleshed peach cultivar (data unpublished). Among the above volatiles, benzyl alcohol has a characteristic pleasant, fruity odor, and a slightly pungent odor note [29]. The odor of 1-octen-3-ol is sweet, earthy, herbaceous, rose, and mushroom-like, and it is considered the most important C8 mushroom volatile aromatic compound and a new natural product for use as a flavoring agent in the food industry [35]. 3-Octanone gives not only a mushroom-like odor [36] but also fruit and lavender odors. 1-Heptanol delivers a fragrant, fruity, and peach-like odor note [11]. As compared with the yellow-fleshed peach JY, the white-fleshed peach HJML was characterized by a unique aroma in this study, which is identical to the results of Beltran and Stange [37]. The above 11 odor-important volatile compounds with significant differences in concentrations between the two cultivars include one ester, three aldehydes, three alcohols, one terpene, and three other volatiles, which is similar to the conclusion drawn by Zhu et al. [38], who pointed out that the different aroma characteristics between the white-fleshed nectarine and its yellow-fleshed mutant were mainly determined by terpenes, phenols, and alcohols.

The color of yellow-fleshed peach is produced by a group of carotenoids, which is one of the qualities that determine the commercial value of peach fruit [39]. Apart from acting as the main reason for the color differences between white- and yellow-fleshed peaches, carotenoids accumulation and degradation also affect the flavor quality of both to some extent [40]. It has been reported that carotenoids could be degraded into compounds of less than 15 carbon atoms, which are the source of the odor characteristics of fruits and flowers during ripening and blossoming, especially C13, C11, C10, and C9 derivatives, and the great diversity of carotenoid chemical structures combined with different degradation pathways may produce a large number of flavors and aromas [41–43]. For example, the C11 derivative—dihydroactinidiolide—is a bicycle lactone with high chemical

stability detected from a natural source. Ionone and damascone are the usual degradation products of carotenoids, and they exist as different isomeric forms such as α-, β-, and γ-ionone/damascone [42]. Tieman et al. [44] found that emissions of carotenoid-derived volatiles were directly correlated with the fruit carotenoid content. In this study, β-ionone was found to be the common odor-important terpene compound detected in two cultivars, and its concentrations showed no significant difference, which may result from differences in the levels of carotenoids accumulation between HJML and JY during fruit ripening. Serra [42] reported that the karahana ether is a C10 volatile compound, which possesses a pleasant camphor-like odor, and the degradation product of carotenoids—theaspirane—is appreciated as a flavor ingredient. There was an ether volatile compound in this study—theaspirane—which was exclusive to white-fleshed peach HJML and possibly indicated that a certain kind of carotenoid is completely degraded to produce theaspirane in white-fleshed peach while existing in the form of a pigment in yellow-fleshed peach.

Carotenoids will produce pigments, hormones, and aroma-related volatile compounds through a series of reactions under the action of enzymes such as carotenoid cleavage dioxygenases (CCDs) and 9-cis-epoxycarotenoid dioxygenases (NCEDs) [9]. Previous studies have shown that isoprenoid volatiles are formed from carotenoids in fruits [45,46]. For instance, β-ionone, dihydro-β-ionone [47,48], citral, and 6-methyl-5-hepten-2-one are generated through cleaving carotenoids at 9,10 and 9′,10′ bonds by the CCD1 enzyme in fruit [42,49,50]. In this study, the volatiles of white- and yellow-fleshed peach fruit were analyzed by HS-SPME/GC-MS. Quantification, odor activity value evaluations and odor notes analysis, and molecular mechanisms in the formation of these differences are still to be explored, such as the regulation mechanisms in the biosynthesis of volatile compounds in white- and yellow-fleshed peach.

5. Conclusions

In conclusion, there were common fruity, floral, sweet, fatty, green, and peach-like odor notes in both the white-fleshed peach represented by HJML and the yellow-fleshed peach represented by JY, being mainly contributed by hexyl acetate, γ-decalactone, benzaldehyde, heptanal, decanal, (E,E)-2,4-decadienal, (E,E)-2,4-nonadienal, (E,E)-2,4-nonadienal, 3-hexenal, (E)-2-octenal, (E)-2-hexenal, 2-heptenal, linalool, β-ionone, and 1-octen-3-one, a total of 15 odor-active compounds (Figure 6). Meanwhile, (E)-2-nonenal, 1-pentanol, and styrene, a total of three odor-active compounds, were perceived as stronger fusel-like and balsamic odor notes in HJML; while (Z)-3-hexenyl acetate, octanal, nonanal, and 3,5-octadien-2-one, a total of four odor-active compounds, were perceived as having stronger banana, citrus-like, and honey odor notes in JY. Moreover, the white-fleshed peach was distinguished from the yellow-fleshed peach fruit by the unique woody, earthy, mushroom, and lavender odor notes due to the presence of the four specific odor-active compounds. As melting fresh peach cultivars with different flesh colors, although their aroma characteristics are different, the two peaches both have strong aromas and are popular with different consumer groups.

Author Contributions: Conceptualization, W.L., Y.Z., R.M. and M.Y.; methodology, W.L. and Y.Z.; software, W.L.; validation, W.L.; formal analysis, W.L.; investigation, W.L. and Y.Z.; resources, W.L., Y.Z., R.M. and M.Y.; data curation, W.L. and Y.Z.; writing—original draft preparation, W.L.; writing—review and editing, W.L., Y.Z., R.M. and M.Y.; visualization, W.L. and Y.Z.; supervision, R.M. and M.Y.; project administration, W.L., Y.Z., R.M. and M.Y.; funding acquisition, Y.Z. and M.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China grant number Grant Number 32002020 and Jiangsu Modern Agricultural Industry Technology System grant number Grant Number JATS 2020 379, JATS 2021 425.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Cao, K.; Yang, X.W.; Li, Y.; Zhu, G.R.; Fang, W.C.; Chen, C.W.; Wang, X.W.; Wu, J.L.; Wang, L.R. New high-quality peach (*Prunus persica* L. Batsch) genome assembly to analyze the molecular evolutionary mechanism of volatile compounds in peach fruits. *Plant J.* **2021**, *108*, 281–295. [CrossRef] [PubMed]
2. Shen, Z.J.; Ma, R.J.; Cai, Z.X.; Xu, J.L. Establishment of peach primary core collection based on accessions conserved in National Fruit Germplasm Repository of Nanjing. *Acta Hortic. Sin.* **2013**, *40*, 125–134.
3. Williamson, G.D.; Peace, C.P.; Bliss, F.A.; Garner, D.T.; Crisosto, C.H. Evidence for a single locus controlling flesh color, senescent leaf color, and hypanthium color in peach. *J. Am. Soc. Hortic. Sci.* **2006**, *131*, 256–260. [CrossRef]
4. Zhang, J.Y.; Pan, H.F.; Gao, Z.H.; Shu, B.; Qi, Y.J.; Yi, X.K.; Qin, G.H.; Sheng, Y.; Chen, H.L.; Xu, Y.L. Transcriptome analysis of colouration-related genes in two white-fleshed nectarine varieties and their yellow-fleshed mutants. *Biotechnol. Biotechnol. Equip.* **2018**, *32*, 899–907. [CrossRef]
5. Zhou, H.J.; Yu, Z.F.; Ye, Z.W.; Su, M.S. Multiplex analyses of the changes of aromatic compounds during the development of peach fruit using GC-MS and iTRAQ proteomic techniques. *Sci. Hortic.* **2018**, *236*, 96–105. [CrossRef]
6. Giberti, S.; Giovannini, D.; Forlani, G. Carotenoid cleavage in chromoplasts of white and yellow-fleshed peach varieties. *J. Sci. Food Agric.* **2019**, *99*, 1795–1803. [CrossRef]
7. Gil, M.I.; Tomä-S-Barberän, F.A.; Hess-Pierce, B.; Kader, A.A. Antioxidant capacities, phenolic compounds, carotenoids, and vitamin C contents of nectarine, peach, and plum cultivars from California. *J. Agric. Food Chem.* **2002**, *50*, 4976–4982. [CrossRef]
8. Qin, J.; Yu, F.; Liu, L.; Zhu, T.T.; Chen, W.; Cao, S.F.; Yang, Z.F.; Shi, L.Y. Cloning of peach PpNAC19 and its regulation on the activity of PpCCD4 promoter. *J. Nucl. Agric. Sci.* **2021**, *35*, 1273–1280.
9. Sun, T.H.; Li, L. Toward the 'golden' era: The status in uncovering the regulatory control of carotenoid accumulation in plants. *Plant Sci.* **2020**, *290*, 110331. [CrossRef]
10. Penso, G.A.; Santos, C.E.M.D.; Bruckner, C.H.; Costa, J.C.F.D.; Citadin, I. Consumption, preferences and habits of purchasing consumers of peaches and nectarines. *Rev. Bras. Frutic.* **2018**, *40*. [CrossRef]
11. Xin, R.; Liu, X.H.; Wei, C.Y.; Yang, C.; Liu, H.R.; Cao, X.M.; Wu, D.; Zhang, B.; Chen, K.S. E-Nose and GC-MS reveal a difference in the volatile profiles of white- and red-fleshed peach fruit. *Sensors* **2018**, *18*, 765. [CrossRef] [PubMed]
12. Raffo, A.; Nardo, N.; Tabilio, M.R.; Paoletti, F. Effects of cold storage on aroma compounds of white- and yellow-fleshed peaches. *Eur. Food Res. Technol.* **2008**, *226*, 1503–1512. [CrossRef]
13. Zhu, Y.Q.; Li, Q.W.; Zeng, W.F.; Niu, L.; Pan, L.; Cai, Z.G.; Cui, G.Z.; Wang, Z.Q. Analysis of volatile aromatic compounds of CN9 nectarine and its yellow-fleshed mutant. *Jiangsu Agric. Sci.* **2018**, *46*, 172–177.
14. Wang, G.Z.; Wang, G.X.; Liang, L.S.; Ma, Q.H. Recent progress in research on the composition and synthesis of aroma volatiles in peach fruits. *Food Sci.* **2014**, *35*, 278–284.
15. Wang, Y.J.; Yang, C.X.; Li, S.H.; Yang, L.; Wang, Y.N.; Zhao, J.B.; Jiang, Q. Volatile characteristics of 50 peaches and nectarines evaluated by HP-SPME with GC-MS. *Food Chem.* **2009**, *116*, 356–364. [CrossRef]
16. Xi, W.P.; Yu, S.L.; Zhou, Z.Q. Advances in aroma compounds biosynthesis of peach fruit. *Acta Hortic. Sin.* **2013**, *40*, 1679–1690.
17. Pino, J.A.; Trujillo, R. Characterization of odour-active compounds of sour guava (*Psidium acidum* [DC.] Landrum) fruit by gas chromatography-olfactometry and odour activity value. *Flavour Fragr. J.* **2020**, *36*, 207–212. [CrossRef]
18. Visai, C.; Vanoli, M. Volatile compound production during growth and ripening of peaches and nectarine. *Sci. Hortic.* **1997**, *70*, 15–24. [CrossRef]
19. Zhang, B.; Shen, J.Y.; Wei, W.W.; Xi, W.P.; Xu, C.J.; Ferguson, I.; Chen, K.S. Expression of genes associated with aroma formation derived from the fatty acid pathway during peach fruit ripening. *J. Agric. Food Chem.* **2010**, *58*, 6157–6165. [CrossRef]
20. Horvat, R.J.; Chapman, G.W.; Robertson, J.A.; Meredith, F.I.; Scorza, R.; Callahan, A.M.; Morgens, P. Comparison of the volatile compounds from several commercial peach cultivars. *J. Agric. Food Chem.* **1990**, *38*, 234–237. [CrossRef]
21. Eduardo, I.; Chietera, G.; Bassi, D.; Rossini, L.; Vecchietti, A. Identification of key odor volatile compounds in the essential oil of nine peach accessions. *J. Sci. Food Agric.* **2010**, *90*, 1146–1154. [CrossRef] [PubMed]
22. Aubert, C.; Bony, P.; Chalot, G.; Landry, P.; Lurol, S. Effects of storage temperature, storage duration, and subsequent ripening on the physicochemical characteristics, volatile compounds, and phytochemicals of Western Red nectarine (*Prunus persica* L. Batsch). *J. Agric. Food Chem.* **2014**, *62*, 4707–4724. [CrossRef] [PubMed]
23. Cai, H.F.; An, X.J.; Han, S.; Jiang, L.; Yu, M.L.; Ma, R.J.; Yu, Z.F. Effect of 1-MCP on the production of volatiles and biosynthesis-related gene expression in peach fruit during cold storage. *Postharvest Biol. Technol.* **2018**, *141*, 50–57. [CrossRef]
24. Cai, H.F.; Han, S.; Jiang, L.; Yu, M.L.; Ma, R.J.; Yu, Z.F. 1-MCP treatment affects peach fruit aroma metabolism as revealed by transcriptomics and metabolite analyses. *Food Res. Int.* **2019**, *122*, 573–584. [CrossRef]
25. Leng, P.; Hu, H.W.; Cui, A.H.; Tang, H.J.; Liu, Y.G. HS-GC-IMS with PCA to analyze volatile flavor compounds of honey peach packaged with different preservation methods during storage. *LWT-Food Sci. Technol.* **2021**, *149*, 111963. [CrossRef]
26. Yang, C.; Duan, W.Y.; Xie, K.L.; Ren, C.H.; Zhu, C.Q.; Chen, K.S.; Zhang, B. Effect of salicylic acid treatment on sensory quality, flavor-related chemicals and gene expression in peach fruit after cold storage. *Postharvest Biol. Technol.* **2020**, *161*, 111089. [CrossRef]
27. Zhou, H.J.; Du, J.H.; Zhang, X.N.; Su, M.S.; Xiong, W.; Ye, Z.W. Effects of UVC pretreatment on composition and content of volatile substances of 'Jinxiang' yellow peach during cold storage and shelf-life. *Acta Agric. Shanghai* **2021**, *37*, 91–99.

28. Wei, S.H.; Xiao, X.M.; Wei, L.J.; Li, L.S.; Li, G.C.; Liu, F.H.; Xie, J.M.; Yu, J.H.; Zhong, Y. Development and comprehensive HS-SPME/GC-MS analysis optimization, comparison, and evaluation of different cabbage cultivars (*Brassica oleracea* L. var. capitata L.) volatile components. *Food Chem.* **2021**, *340*, 128166. [CrossRef]
29. Burdock, G.A. *Fenaroli's Handbook of Flavor Ingredients*; CRC Press: Boca Raton, FL, USA; Taylor & Francis: Boca Raton, FL, USA, 2010.
30. Ceccarelli, A.; Farneti, B.; Frisina, C.; Allen, D.; Donati, I.; Cellini, A.; Costa, G.; Spinelli, F.; Stefanelli, D. Harvest maturity stage and cold storage length influence on flavour development in peach fruit. *Agronomys* **2018**, *9*, 10. [CrossRef]
31. Li, Y.X.; Wang, G.X.; Liang, L.S. The changes of volatile compositions of 'Okubo' peach and its relationship with ethylene and relevant enzymes stored at ambient temperature. *Acta Hortic. Sin.* **2009**, *38*, 35–42.
32. Fan, X.; Cui, X.P. Based on HS-SPME/GC-MS and electronic nose technology to study the aroma compounds of peach of different flesh types during the July postharvest storage in Jiangsu Province. *Food Sci.* **2021**, *42*, 222–229.
33. Schieberle, P.; Grosch, W. Potent odorants of the wheat bread crumb—Differences to the crust and effect of a longer dough fermentation. *Z. Lebensm.-Unters. Forsch.* **1991**, *192*, 130–135. [CrossRef]
34. Zhang, Y.T.; Dong, J.; Wang, G.X. Formation of aroma volatiles in strawberry fruit and aroma breeding. *Sci. Agric. Sin.* **2004**, *37*, 1039–1044.
35. Maggi, F.; Bílek, T.; Lucarini, D.; Papa, F.; Sagratini, G.; Vittori, S. *Melittis melissophyllum* L. subsp. *melissophyllum* (Lamiaceae) from central Italy: A new source of a mushroom-like flavour. *Food Chem.* **2009**, *113*, 216–221.
36. Elsharif, S.A.; Buettner, A. Structure-odor relationship study on geraniol, nerol, and their synthesized oxygenated derivatives. *J. Agric. Food Chem.* **2018**, *66*, 2324–2333. [CrossRef]
37. Beltran, J.C.; Stange, C. Apocarotenoids: A new carotenoid-derived pathway. *Carotenoids Nat.* **2016**, *79*, 239–272.
38. Zhu, J.C.; Xiao, Z.B. Characterization of the key aroma compounds in peach by gas chromatography-olfactometry, quantitative measurements and sensory analysis. *Eur. Food Res. Technol.* **2018**, *245*, 129–141. [CrossRef]
39. Cao, S.F.; Liang, M.H.; Shi, L.Y.; Shao, J.R.; Song, C.B.; Bian, K.; Chen, W.; Yang, Z.F. Accumulation of carotenoids and expression of carotenogenic genes in peach fruit. *Food Chem.* **2017**, *214*, 137–146. [CrossRef]
40. Zhang, Y.; Liu, L.Q.; Duan, Y.R.; Wu, J.K.; Zhang, L.B. Research progress on color formation mechanism of peach flesh. *Hebei Fruits* **2018**, *6*, 1–4.
41. Mendes-Pinto, M.M. Carotenoid breakdown products the-norisoprenoids-in wine aroma. *Arch Biochem. Biophys.* **2009**, *483*, 236–245. [CrossRef]
42. Serra, S. Recent advances in the synthesis of carotenoid-derived flavours and fragrances. *Molecules* **2015**, *20*, 12817–12840. [CrossRef] [PubMed]
43. Walter, M.H.; Strack, D. Carotenoids and their cleavage products: Biosynthesis and functions. *Nat. Prod. Rep.* **2011**, *28*, 663–692. [CrossRef] [PubMed]
44. Tieman, D.M.; Zeigler, M.; Schmelz, E.A.; Taylor, M.G.; Bliss, P.; Kirst, M.; Klee, H.J. Identification of loci affecting flavour volatile emissions in tomato fruits. *J. Exp. Bot.* **2006**, *57*, 887–896. [CrossRef] [PubMed]
45. Cheng, L.; Huang, N.; Jiang, S.Z.; Li, K.; Zhuang, Z.; Wang, Q.; Lu, S. Cloning and functional characterization of two carotenoid cleavage dioxygenases for ionone biosynthesis in chili pepper (*Capsicum annuum* L.) fruits. *Sci. Hortic.* **2021**, *288*, 110368. [CrossRef]
46. Ilg, A.; Bruno, M.; Beyer, P.; Al-Babili, S. Tomato carotenoid cleavage dioxygenases 1A and 1B: Relaxed double bond specificity leads to a plenitude of dialdehydes, mono-apocarotenoids and isoprenoid volatiles. *FEBS Open Bio* **2014**, *4*, 584–593. [CrossRef]
47. Bouvier, F.; Isner, J.C.; Dogbo, O.; Camara, B. Oxidative tailoring of carotenoids: A prospect towards novel functions in plants. *Trends Plant Sci.* **2005**, *10*, 187–194. [CrossRef]
48. Paparella, A.; Shaltiel-Harpaza, L.; Ibdah, M. β-Ionone: Its occurrence and biological function and metabolic engineering. *Plants* **2021**, *10*, 754. [CrossRef]
49. Lewinsohn, E.; Sitrit, Y.; Bar, E.; Azulay, Y.; Meir, A.; Zamir, D.; Tadmor, Y. Carotenoid pigmentation affects the volatile composition of tomato and watermelon fruits, as revealed by comparative genetic analyses. *J. Agric. Food Chem.* **2005**, *53*, 3142–3148. [CrossRef]
50. Vogel, J.T.; Tan, B.C.; McCarty, D.R.; Klee, H.J. The carotenoid cleavage dioxygenase 1 enzyme has broad substrate specificity, cleaving multiple carotenoids at two different bond positions. *J. Biol. Chem.* **2008**, *283*, 11364–11373. [CrossRef]