Characteristic volatile organic compounds in “HeTao” melon and other cultivars grown in Hetao region analyzed by HS-GC-IMS

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Abstract

The headspace-gas chromatography-ion mobility spectrometry (HS-GC-IMS) was used to compare the volatile organic components of the Hetao melon and six other cultivars of melon grown in the Hetao region of China. The results showed that the common VOCs that could be qualitatively identified from the 7 different melon samples were 35 monomers and dimers of certain compounds, mainly including alcohols, esters, aldehydes, terpenes, acids and pyridines. Hexyl acetate, 3-methylbutyl acetate, ethyl acetate and ethyl formate were predominant VOCs in seven melon cultivars. Among them, Xizhoumi No. 25 (XZM25) had 3 unique volatile organic components: 3-methylbutanal, benzaldehyde and nonanal. Xizhoumi No. 17 (XZM17) had 3 unique volatile organic components: alpha-pinene, linalool and (E)-2-hexenol. Jinhongmi (JHM) had 1 unique volatile organic component: ethyl pentanoate. The Hetao melon (HLS) contained 3 unique volatile organic components: heptanal, 2-ethyl-6-methyl pyrazine and 3-methyl valeric acid. Yinmi (YM) had 2 unique volatile organic components: 3-methylbutanol and 1-butanol, and Huangjinmi (HJM) had 1 unique volatile organic component: limonene. YM, GMB2010, HLS and JHM were similar based on the principal component analysis. This research analyzed the flavor components of different melon cultivars grown in the Hetao region of China for the first time.

Keywords Cucumis melo · HS-GC-IMS · Volatile organic compounds · Fingerprint · Principal component analysis

1 Introduction

Melon (*Cucumis melo* L.) is a crop that is widely cultivated and consumed in the world. Melon is widely accepted by people because of its nutrients, including malic acid, vitamin A, B, C, niacin, calcium, phosphorus, iron and other elements [1]. Of the fresh melon aroma components, the predominant chemicals are heterogeneous groups of VOCs, consisting of esters, alcohols and aldehydes [2]. The aromas of different cultivars vary greatly. According to the different volatile aromatic substances emitted, aromas can be characterized as fruity, floral, and “cucumber” types [3]. For detecting VOCs, HS-GC-IMS is a detection technology

that combines gas chromatography and ion mobility spectroscopy [4]. This detection technology overcomes the limitation of poor separation of ions in mobility spectroscopy technology and significantly improves the ion mobility spectrum signal response after gas phase pre-separation [5]. With the drift time of the ion mobility spectrum, the system provides more abundant chemical information after gas chromatographic separation. By combining the advantages of gas chromatography and ion mobility spectroscopy technologies, HS-GC-IMS has the advantages of fast speeds, high sensitivity, no pre-processing and simple operation. It is widely used in food flavor analysis [6–10], quality inspection [11, 12] and other fields [13].

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In this study, we selected seven cultivars of muskmelon grown in the Hetao region to compare the differences in their characteristic volatile organic compounds. “Hetao” melon (*Cucumis melon* L.cv. *Hetao*) is a specialty of Bayannaoer city and a geographical indication of China agricultural products. “Hetao” melon is also called “HuaLaishi” melon in the Hetao region [14]. In this study we used the abbreviation “HLS” to represent “Hetao” melon. “Xizhoumi No. 25” muskmelon (*Cucumis melon* var. *saccharinus* Naud.) (XZM 25) and “Xizhoumi No. 17” muskmelon (*Cucumis melon* var. *saccharinus* Naud.) (XZM 17) are popular cultivars in Xinjiang Uygur Autonomous Region. “Ganmibao2010” melon (*Cucumis melon* var. *reticulatus* Naud.) (GMB2010), “Jinhongmi” melon (*Cucumis melon* var. *inodorus* Naud.) (JHM) and “Yinmi” melon (*Cucumis melon* var. *inodorus* Naud.) are specialties of Gansu province. “Huangjinmi” melon (*Cucumis melon* var. *reticulatus* Naud.) (HJM) is a specialty of Anhui province.

The Hetao region of Inner Mongolia is located along the banks of the Yellow River. The sunny season is long, the temperature difference between day and night is large, and the climatic environment is arid and rainless. It provides an optimal growth environment for melons [15]. By analyzing melons’ VOCs, this study illustrates the unique flavor compositions of different cultivars of melon and provides a factual basis for systematic and in-depth research on the development of melons’ flavors, especially sugar accumulation and intrinsic enzymatic mechanisms during the melons’ ripening.

2 Materials and methods

2.1 Sample preparation

Melons were harvested from the Dengkou County, Bayannaoer City. All the experimental melons were cleaned and stored in a cool place at room temperature after harvest. The size and weight of these seven melon samples are consistent.

2.2 HS-GC-IMS analysis

The volatile organic compounds of melon pulp were analyzed using a headspace-gas chromatography ion mobility spectrometry instrument (FlavourSpec® Shandong Haineng Scientific Instrument Co., Ltd. G.A.S Division). The instrument was equipped with an autosampler which involves a headspace sampling unit and a 1 ml gas tight syringe. The gas chromatographic column type used was FS-SE-54-CB-1 (ID: 0.53 mm) and the length of the gas chromatographic column was 15 m. The column temperature was set at 60 °C. All samples were prepared as follows: 2 g

of melon pulp were cut from the middle of the melon and placed in a 20 ml headspace bottle. The sample was incubated at 40 °C for 15 min under rotation at 500 rpm (revolutions per minute). After incubation, 500 µL of headspace was injected with a 45 °C air-tight syringe into the 60 °C column. The analytes were separated in the gas chromatographic column with nitrogen (99.99% purity) gas as a carrier. The flow rates of the carrier gas were programmed as follows: 2 ml/min for 2 min, then a 2 ml/min linear rise to 100 ml/min in 18 min. The total running time of the program was 20 min. Upon exiting the column, analytes were ionized by the tritium ionization source in the IMS ionization chamber. Finally, ions were separated using nitrogen gas (99.99%) flowing in the drift tube at a constant rate of 150 ml/min at a temperature of 45 °C. Each experimental sample was tested 3 times.

2.3 Data analysis

The main software used for analyzing volatile organic compounds was laboratory analytical viewer (LAV) with three plug-ins. LAV can draw a quantitative analysis spectrum (3D Spectrogram). The horizontal axis is drift time (DT) and the vertical axis is retention time (RT) in the GC-IMS Spectrogram. Each point in the figure represents a volatile organic compound. The external references of retention index (RI) used n-alkanes C4-C9, to establish the standard curve. By comparing the RI and DT with standard data in the NIST and IMS databases of GC × IMS Library Search, all the volatile components were determined. The reporter plug-in directly compares the differences in spectrograms between samples by two-dimensional top view spectrogram. The gallery plot plug-in intuitively compares the differences in volatile organic compounds among different samples in the fingerprint. The dynamic principle component analysis (PCA) plug-in was used to cluster samples and evaluate the relationships among samples.

Means and nonparametric tests of peak volumes of melon pulp from seven cultivars were calculated based on three independent replicates of each cultivar (n = 3). Analysis of variance and $P < 0.05$ was used to identify significant differences among the samples. The software selected to carry out statistical tests was SPSS 21.0 (IBM SPSS Inc, USA).

3 Results and discussion

3.1 Qualitative analysis of volatile organic compounds in melons by HS-GC-IMS

The contribution to the overall flavor was determined by the concentration of volatile components in the flavor system and the sensory threshold [16]. The qualitative

analysis of the volatile organic compounds detected by HS-GC-IMS in seven different kinds of cantaloupe, and the distribution of the flavor substances are shown in Fig. 1. The red vertical line at 1.0 of the horizontal axis represents the reactive ion peak (RIP), the horizontal axis represents the drift time (relative to RIP) and the vertical axis represents retention time. The migration time of RIP was set at 7.89 ms as a reference, so the influence of temperature and pressure deviations could be avoided in the detection process. Each spot on the both sides of the RIP line represents one type of volatile organic component.

The red spot indicate higher abundance VOCs, while the white spots indicate lower abundance VOCs. Most VOCs signals were detected with retention times of 100 to 400 s and with drift times ranging between 1.0 and 2.0

relative to RIP. Several volatile organic compounds were present as both monomers and dimers. Table 1 identifies every numbered spot in Fig. 1, 35 volatile compounds were found by this experiment, including 17 esters, 5 alcohols, 4 aldehydes, 1 pyrazine, 2 terpenoids and 1 acid. As shown in Fig. 1, hexyl acetate, 3-methylbutyl acetate, butyl acetate, 2-methylpropyl- acetate, ethyl propanoate, ethyl acetate and ethyl formate were the most abundant. This result implies that esters, as characteristic compounds found in muskmelons, play an important role in the flavor of melon pulp. We determined that gamma-octa lactone, nonanal, linalool and propyl hexanoate have longer retention times. Ethanol and benzaldehyde have shorter drift times.

Fig. 1 Qualitative analysis of volatile organic compounds in melons

Table 1 Qualitative analysis of main volatile organic compounds in melons

Count	Compound	CAS#	Formula	MW	RI	Rt [sec]	Dt [relRIP]
1	Gamma-octa lactone	C104507	C8H14O2	142.2	1186.4	608.179	1.3327
2	Nonanal	C124196	C9H18O	142.2	1109.3	491.794	1.5013
3	Linalool	C78706	C10H18O	154.3	1092.0	465.62	1.2289
4	Hexyl acetate-M	C142927	C8H16O2	144.2	1020.3	363.299	1.3849
5	Hexyl acetate-D	C142927	C8H16O2	144.2	1020.4	363.411	1.8926
6	Ethyl hexanoate-M	C123660	C8H16O2	144.2	1010.1	350.575	1.3377
7	Ethyl hexanoate-D	C123660	C8H16O2	144.2	1010.9	351.526	1.8089
8	2-Ethyl-6-methyl pyrazine	C13925036	C7H10N2	122.2	993.1	331.083	1.1721
9	Benzaldehyde	C100527	C7H6O	106.1	964.3	302.557	1.1464
10	Alpha-Pinene	C80568	C10H16	136.2	943.8	285.442	1.2268
11	Methyl hexanoate	C106707	C7H14O2	130.2	931.2	275.934	1.2879
12	Methyl hexanoate	C106707	C7H14O2	130.2	929.2	274.508	1.6964
13	Amyl acetate	C628637	C7H14O2	130.2	919.7	267.852	1.3104
14	Amyl acetate	C628637	C7H14O2	130.2	919.7	267.852	1.7591
15	3-Methylbutyl acetate	C123922	C7H14O2	130.2	884.7	245.983	1.735
16	Ethyl 2-methylbutanoate	C7452791	C7H14O2	130.2	851.0	227.556	1.2497
17	Ethyl 2-methylbutanoate	C7452791	C7H14O2	130.2	847.1	225.543	1.65
18	(E)-2-hexenol	C928950	C6H12O	100.2	845.9	224.968	1.1758
19	Butyl acetate	C123864	C6H12O2	116.2	811.0	208.006	1.615
20	2-Methylpropyl acetate	C110190	C6H12O2	116.2	770.8	189.894	1.611
21	Ethyl butanoate	C105544	C6H12O2	116.2	797.2	201.638	1.5548
22	ethyl propanoate	C105373	C5H10O2	102.1	716.0	167.683	1.4509
23	Propyl acetate	C109604	C5H10O2	102.1	670.2	152.794	1.4731
24	3-methylbutanal	C590863	C5H10O	86.1	660.4	150.07	1.4031
25	Ethyl Acetate	C141786	C4H8O2	88.1	610.9	137.723	1.333
26	Ethyl formate	C109944	C3H6O2	74.1	523.5	117.568	1.1883
27	Ethanol	C64175	C2H6O	46.1	495.9	111.213	1.0378
28	Propyl hexanoate	C626777	C9H18O2	158.2	1106.9	488.065	1.4119
29	Ethyl pentanoate	C539822	C7H14O2	130.2	904.7	258.003	1.6776
30	Ethyl2-methylpropanoate	C97621	C6H12O2	116.2	774.4	191.457	1.5634
31	Heptanal	C111717	C7H14O	114.2	904.8	258.069	1.6946
32	3-Methyl valeric acid	C105431	C6H12O2	116.2	943.2	284.973	1.6039
33	Limonene	C138863	C10H16	136.2	1025.2	369.552	1.2172
34	3-methylbutanol	C123513	C5H12O	88.1	743.5	178.341	1.3441
35	1-Butanol	C71363	C4H10O	74.1	696.6	160.902	1.3859

3.2 Qualitative analysis of different VOCs in seven cultivars of melons

As shown in Fig. 2, the volatile organic compounds of the seven samples exhibited differences among them. The characteristic volatile organic compounds of these seven varieties of melons appeared with drift times of 1.0–1.9 and the retention times of 100–400 s. In order to more clearly compare the differences among the samples, a comparison topographic was used. As shown in Fig. 3, the GC-IMS topographic of HLS was selected as a reference, and the other samples' topographic plots were deducted from the reference (see Fig. 3).

After deduction, if the concentration of VOCs in other samples was similar to the reference, the color of the specific organic component would be white, while a red color indicates that the concentration of the compound in the sample is higher than in the reference. A compound's blue color in each comparison topographic implies that the concentration of the substance in the sample is lower than in the reference. As shown in Fig. 3, there is an obvious tendency for the volatile organic components of XZM17, JHM, XZM25 and HJM to have a higher concentration than the reference in the drift times between 1.0 and 1.5, while their VOCs were lower in concentration than the reference in the drift times between 1.5 and 1.9. What's more, it can

Fig. 2 GC-IMS topographic plots of volatile organic compounds in seven cultivars of melons

Fig. 3 Comparison of GC-IMS topographic of seven varieties of muskmelons with HLS as a reference

be seen that the colors of the GC-IMS topographics of GMB2010 and YM are close to white, which means that the VOCs in these two samples are similar to HLS. This result is also consistent with the principal component analysis.

In order to better compare the differences in VOCs among the different samples, we framed the peaks of these compounds to create sample fingerprints for each melon cultivar (see Fig. 4). Rows in the figureprints

Fig. 4 The VOCs fingerprints of seven cultivars of melon

represent all the signal peaks selected from the melon samples, and each column represents the signal peaks of the same volatile organic compound in the different peach samples. Figure 4 shows the complete VOC information for each sample and the differences in VOCs among samples. Some of the volatile organic compounds were detected by the GC-IMS instrument but were not found in the built-in NIST and IMS databases. So, these VOCs were numbered from one to fifteen.

Two different color wireframes were used to mark different areas of the fingerprints collected from the seven cultivars of melons. The area in the red wireframe represents esters, which are very abundant among the seven cultivars of melons. The area in the yellow wireframe represents other kinds of volatile organic compounds that are unique in certain types of melons or have much higher concentrations in some cultivars than in others. As shown in Fig. 4, the ester compounds are the main flavor compounds in melons. The concentrations of esters in XZM17, XZM25 and HJM is low, while the concentrations of esters in the other four samples is higher. Each cultivar of melons also has its own unique flavor compounds. In XZM17, the concentrations of alpha-pinene, linalool and (E)-2-hexenol are higher than in other samples. In XZM25, benzaldehyde, nonanal and 3-methylbutanal are higher than in other samples. In HJM, ethyl pentanoate is higher than in other samples. In HLS,

heptanal, 2-ethyl-6-methyl pyrazine and 3-methyl valeric acid are higher than in other samples. In HJM, limonene is higher than in other samples. In YM, 3-methylbutanol and 1-butanol are higher than in other samples.

3.3 Quantitative analysis of different VOCs in seven varieties of melons

For quantitative analysis, an accurate data is required. In this study, the peak volume of volatile organic compounds in different cultivars was exactly recorded by the HS-GC-IMS instrument. So, the original graph generated by the HS-GC-IMS instrument is a three-dimensional graph, where the X-axis represents the drift time obtained from the drift tube in the IMS, the Y-axis represents the retention time obtained from the GC, and the Z-axis represents the quantitative intensity of the peak volume. As shown in Fig. 5, each peak on the right side of the RIP has different sizes and a very scattered distribution.

By calculating and comparing the peak volumes, we gained a deep understanding about the specific VOCs that differed among the samples and about the specific ratios of different VOCs in one cultivar. For the convenience of calculation, we had combined the monomer and dimer data. Table 2 illustrates the relative content of different VOCs in each cultivar. The relative content value was

Fig. 5 Three-dimensional graph of VOCs in melon pulp samples

calculated with the following formula: the peak volume of a specific VOC was divided by the sum of all the VOC peak volumes of that cultivar. We conducted a nonparametric test to examine the differences among the different cultivars in the same volatile organic compound.

As shown in Table 2, among the seven cultivars, all have the same four major kinds of volatile organic compounds (hexyl acetate, 3-methylbutyl acetate, ethyl acetate, ethyl formate). Their relative contents were higher than 10%, especially ethyl acetate, which represents 26.52% of all the VOCs in HJM. So, hexyl acetate, 3-methylbutyl acetate, ethyl acetate and ethyl formate are the most contributors to melon aroma in this study. As for the relative contents of nonanal, linalool, 2-ethyl-6-methyl pyrazine, benzaldehyde, alpha-pinene, e-2-hexenol, propyl hexanoate, ethyl pentanoate, heptanal, 3-methyl valeric acid and limonene, all were lower than 1%. So, their contributions to the flavor might be masked by the other VOCs.

Table 3 illustrates the relative content of the same VOC in different cultivars. The relative content value was calculated by the following formula: in the row of the same volatile organic compounds, the largest organic compound peak volume among the seven cultivars was selected as the reference, and the other samples were divided by this reference value to obtain the relative content. When aromatic melon cultivars in climacteric, volatile esters are prominent, together with sulphur-containing aroma compounds, sesquiterpenes, norisoprenes, short-chain alcohols, and aldehydes [17]. In C Aubert's study [18], volatile esters, mainly acetate derivatives such as ethyl 2-methyl propyl acetate and 2-methyl butyl acetate are dominant with 37% of the total volatile profile in melons. As shown

in Table 3, the HLS cultivar had the highest content of hexyl acetate, ethyl hexanoate, 2-ethyl-6-methyl pyrazine, amyl acetate, 3-methylbutyl acetate, butyl acetate, ethyl butanoate, ethyl propanoate, ethyl 2-methylpropanoate, heptanal, 3-methyl valeric acid and ethanol. The XZM17 cultivar had the highest content of linalool, alpha-pinene, e-2-hexenol, 2-methylpropyl acetate, propyl acetate and ethyl formate. The JHM cultivar had the highest content of gamma-octalactone, ethyl acetate, propyl hexanoate and ethyl pentanoate. The XZM25 cultivar had the highest content of nonanal, benzaldehyde and 3-methylbutanol. The YM cultivar had the highest content of methyl hexanoate, ethyl 2-methylbutanoate, 3-methylbutanal and 1-butanol. The HJM cultivar had the highest content of limonene. In summary, the HLS cultivar has the highest content in seven different ester compounds. Among them, ethyl butanoate is the active odor compound in "Elstar" apples [19], hexyl acetate and amyl acetate possess strong pear-like aromas [20], butyl acetate was detected by olfactometric analyses as characteristics of banana odor [21], ethyl hexanoate and ethyl propanoate were considered to be the characteristic aroma compounds for the Tainong No. 6 pineapple [22]. So, that's why HLS cultivar has strong aroma of different fruits.

3.4 Principal component analysis of volatile compounds in seven cultivars of melon

PCA is a multivariate statistical method. Its core idea is to reduce the dimensionality of a data set composed of a large number of related variables, while retaining the changes in the data set as much as possible [23]. In

Table 2 Relative content of different VOCs in each cultivar

No.	Compounds	Relative content of different VOCs in each cultivar							Chi-square	Df	Sig
		XZM17 (%)	JHM (%)	XZM25 (%)	GMB2010 (%)	HLS (%)	HJM (%)	YM (%)			
1	Gamma_octalactone	1.36	3.19	1.28	0.77	1.47	1.62	2.18	16.242	6	0.013
2	Nonanal	0.29	0.19	1.69	0.22	0.1%	1.22	0.23	17.939	6	0.006
3	Linalool	0.33	0.2	0.3	0.17	0.15	0.44	0.15	17.68	6	0.007
4	Hexylacetate	12.87	10.7	7.02	11.26	12.95	10.62	10.2	14.234	6	0.027
5	Ethylhexanoate	1.06	7.75	1.9	5.76	6.86	3.25	7.59	18.355	6	0.005
6	2_Ethyl_6_methylpyrazine	0.18	0.26	0.26	0.06	0.24	0.47	0.07	17.126	6	0.009
7	Benzaldehyde	0.26	0.11	0.57	0.09	0.17	0.74	0.31	19.255	6	0.004
8	Alpha_Pinene	0.74	0.11	0.09	0.16	0.58	0.35	0.18	19.325	6	0.004
9	Methylhexanoate	0.94	0.35	0.54	0.85	0.78	1.28	1.21	19.048	6	0.004
10	Amylacetate	3.14	2.53	3.44	3.43	3.77	2.2	3.14%	16.485	6	0.011
11	3_Methylbutylacetate	13.3	11.29	10.67	12.22	11.83	7.48	10.77	18.771	6	0.005
12	Ethyl2_methylbutanoate	0.78	2.29	2.25	2.41	2.02	1.9	2.8	16.346	6	0.012
13	E_2_hexenol	0.25	0.01	0.03	0.01	0.02	0.12	0.02	18.424	6	0.005
14	Butylacetate	9.55	6.02	4.48	7.35	8.27	3.68	5.52	19.082	6	0.004
15	2_Methylpropylacetate	7.45	5.98	6.27	5.4	4.89	2.35	3.71	19.325	6	0.004
16	Ethylbutanoate	0.78	1.71	1.48	1.7	1.67	1.88	1.53	12.519	6	0.051
17	Ethylpropanoate	7.15	7.99	7	7.48	7.02	6.84	7.8	15.238	6	0.018
18	Propylacetate	2.18	0.03	2.28	0.17	0.05	0.3	0.79	19.636	6	0.003
19	3_methylbutanal	2.24	0.51	3.04	1.48	0.81	1.61	2.33	19.186	6	0.004
20	EthylAcetate	13.07	16.25	17.75	14.46	13.13	26.52	14.09	19.325	6	0.004
21	Ethylformate	17.73	11.46	14.12	13.97	11.38	8.82	14.46	18.216	6	0.006
22	Propylhexanoate	0.11	0.48	0.48	0.28	0.29	0.51	0.44	17.385	6	0.008
23	Ethylpentanoate	0.11	0.99	0.41	0.59	0.73	0.21	0.74	18.113	6	0.006
24	Ethyl2_methylpropanoate	1.19	0.55	1.45	1.21	1.23	1.89	1.37	18.061	6	0.006
25	Heptanal	0.21	0.45	0.21	0.54	0.69	0.14	0.38	19.152	6	0.004
26	3_Methylvalericacid	0.26	0.05	0.06	0.0	1.55	0.13	0.07	18.216	6	0.006
27	Limonene	0.06	0.06	0.16	0.06	0.05	0.52	0.06	16.831	6	0.01
30	3_methylbutanol	0.16	0.82	1.67	0.81	0.5	1.48	0.21	19.048	6	0.004
31	1_Butanol	0.77	0.95	0.88	0.97	0.66	1.05	1.59	16.935	6	0.01
32	Ethanol	1.49	6.88	8.21	6.05	6.13	10.41	6.03	18.216	6	0.006

this study, principal component analysis of the volatile compounds in seven cultivars of melon was carried out. The data is visualized, and the distribution diagram of the first two principal components is shown in Fig. 6. Generally speaking, the first few principal components, whose cumulative contribution to the variance reaches more than 80%, can be selected as the final principal components to depict data differentiation [24]. Figure 6 shows that the contribution to the variance of the first two principal components are 44% and 24%.

The seven groups of samples could be well separated, which proves that there are differences in the characteristic flavor substances of the samples. The seven cultivars of melon are roughly located in four areas of the distribution map. HJM, XZM17 and XZM25 represent one type of

melon. YM, GMB2010, HLS and JHM are similar and represent another type of melon, while YM and GMB2010 are the most similar. These findings are also consistent with the results of fingerprint and quantitative analyses of peak volumes.

4 Conclusions

In this study, 35 volatile organic compounds in melons were detected by HS-GC-IMS. Melon aromas included six heterogeneous groups of VOCs, consisting of esters, alcohols, organic acids, aldehydes, terpenes and pyrazines [25]. In particular, the acetate esters comprised 61.5% of the VOC content in XZM17, and the acetate

Table 3 Relative content of the same VOC in different cultivars

No.	Compounds	Relative content of the same VOC in different cultivars							Chi-square	Df	Sig
		XZM17 (%)	JHM (%)	XZM25 (%)	GMB2010 (%)	HLS (%)	HJM (%)	YM (%)			
1	Gamma_octalactone	41.9	100.0	28.4	26.3	55.8	15.8	70.5	18.528	6	0.005
2	Nonanal	24.2	16.1	100.0	20.0	10.6	29.5	20.1	17.887	6	0.007
3	Linalool	100.0	63.4	64.7	55.8	54.6	38.7	47.5	17.489	6	0.008
4	Hexylacetate	80.8	68.3	31.6	78.1	100.0	21.0	67.5	18.84	6	0.004
5	Ethyl hexanoate	12.5	91.6	16.2	75.4	100.0	12.0	94.5	17.177	6	0.009
6	2_Ethyl_6_methylpyrazine	61.2	89.7	61.8	21.8	100.0	48.6	25.6	16.935	6	0.01
7	Benzaldehyde	62.1	28.4	100.0	24.1	50.9	52.6	79.1	19.048	6	0.004
8	Alpha_pinene	100.0	15.4	8.6	23.9	95.3	14.2	25.1	18.805	6	0.005
9	Methyl hexanoate	74.5	27.9	31.0	73.9	75.7	30.2	100.0	17.489	6	0.008
10	Amyl acetate	67.7	55.7	53.6	81.6	100.0	14.6	71.0	19.186	6	0.004
11	3_Methylbutylacetate	91.4	79.0	52.7	92.8	100.0	16.3	77.7	19.082	6	0.004
12	Ethyl2_methylbutanoate	26.5	79.3	55.3	90.8	84.8	19.2	100.0	19.394	6	0.004
13	E_2_hexenol	100.0	6.1	7.5	6.1	8.9	13.7	8.9	17.662	6	0.007
14	Butyl acetate	93.7	60.2	31.6%	79.7	100.0	11.6	56.8	19.636	6	0.003
15	2_Methylpropylacetate	100.0	81.7	60.4	80.1	80.8	10.0	52.1	18.39	6	0.005
16	Ethyl butanoate	38.2	84.9	52.0	91.4	100.0	27.5	78.0	19.498	6	0.003
17	Ethyl propanoate	82.8	94.1	58.4	95.7	100.0	24.0	94.6	18.563	6	0.005
18	Propyl acetate	100.0	1.3	75.2	8.7	3.0	4.2	37.7	19.636	6	0.003
19	3_methylbutanal	92.0	21.2	89.4	67.1	41.0	20.1	100.0	18.372	6	0.005
20	Ethyl acetate	79.0	100.0	77.0	96.6	97.6	48.6	89.2	19.394	6	0.004
21	Ethyl formate	100.0	65.8	57.3	87.0	79.0	14.8	85.5	19.325	6	0.004
22	Propyl hexanoate	22.9	100.0	70.9	62.8	71.3	30.9	93.1	18.563	6	0.005
23	Ethyl pentanoate	11.0	100.0	29.4	65.2	89.8	6.5	77.6	18.597	6	0.005
24	Ethyl2_methylpropanoate	78.5	36.9	68.7	88.2	100.0	37.9	94.8	18.909	6	0.004
25	Heptanal	24.1	54.1	18.2	70.4	100.0	5.0	46.8	19.359	6	0.004
26	3_Methylvalericacid	13.7	2.9	2.4	3.5	100.0	2.0	4.0	19.342	6	0.004
27	Limonene	36.3	38.3	74.0	45.0	37.2	100.0	40.9	14.857	6	0.021
30	3_methylbutanol	13.2	69.9	100.0	74.4	51.5	36.8	18.1	19.394	6	0.004
31	1_Butanol	45.9	58.1	37.8	64.2	48.7	19.0	100.0	19.325	6	0.004
32	Ethanol	19.8	92.9	78.5	88.7	100.0	40.7	83.8	18.771	6	0.005

esters represented 52.8% of the VOC content in JHM. The acetate esters were 51.91% of the VOC content in XZM25, and 54.29% of the VOC content in GMB2010. Likewise, the acetate esters represented 54.89% of the VOC content in HLS, 53.15% in HJM, and 48.27% in YM. If we added the percentage of non-acetate esters, the esters would account for 92.77% of VOC content in XZM17, 89.56% in JHM, 82.82% in XZM25, 89.31% in GMB2010, 88.34% in HLS, 81.35% in HJM and 88.39% in YM. Esters play important roles as flavor and aroma compounds, especially the acetate esters [26]. In this study, the ester compounds were mainly 6–7 carbon chains, and we didn't find sulfur-containing ester compounds. Kourkoutas [27] stated that sulfur-containing ester compounds were mainly six carbon chains and sulfur-free ester compounds were dominated by a 9-carbon chain in three melon cultivars grown in Spain.

As for the unique flavor of each of the cultivars in our study, this might be related to each cultivar's unique VOCs. In general, the genetic makeup, degree of maturity, environmental conditions, postharvest handling and storage factors could affect volatile composition [28]. Biochemical pathways are also responsible for VOCs, including fatty acids pathway, β -oxidation, lipoxigenase, amino acid pathway and carotenoid pathway [28, 29]. Although we know many factors can affect the flavor of melon, we still have a limited understanding of how these factors interact to determine the final volatile composition of the melon. The findings of this study establish a theoretical basis for future research, such as studying the regulation of the accumulation of characteristic VOCs in melon pulp, indicator of breeding new cultivars of melon and improving melon pulp's quality

Fig. 6 Principal component analysis of volatile organic compounds in seven cultivars of melon.

by enhancing the concentration of several specific flavor compounds.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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