Verification of Aroma Profiles of Jiashi Muskmelon Juice Characterized by Odor Activity Value and Gas Chromatography–Olfactometry/Detection Frequency Analysis: Aroma Reconstitution Experiments and Omission Tests

Xueli Pang, Dong Chen, Xiaosong Hu, Yan Zhang, and Jihong Wu*

College of Food Science and Nutritional Engineering, China Agricultural University; Key Laboratory of Fruit and Vegetable Processing, Ministry of Agriculture; and National Engineering Research Center for Fruit and Vegetable Processing, Beijing 100083, China

ABSTRACT: To verify the aroma profile of Jiashi muskmelon previously identified by gas chromatography–olfactometry/ detection frequency analysis (GC-O/DFA) and odor activity value (OAV) calculation, the synthetic blends of odorants (aroma models) were prepared and then were compared with the original Jiashi muskmelon juice aroma using quantitative descriptive analysis (QDA) and electronic nose analysis (ENA), respectively. QDA and ENA both indicated that the model solution derived from OAV calculation more closely resembled the original melon juice aroma than that based on DFA data. Omission tests corroborated the significant contribution of five unsaturated aldehydes and alcohols with nine carbon atoms as well as five branched esters, in particular, the "fruity"-smelling ethyl butanoate and the "cucumber-like" (2E,6Z)-nona-2,6-dienal to Jiashi muskmelon overall aroma.

KEYWORDS: melon, aroma profile, quantitative descriptive analysis (QDA), electronic nose analysis (ENA), aroma reconstitution, omission test

INTRODUCTION

Jiashi muskmelon, or Kalakusai melon, named for its origin in the Jiashi County, is a climacteric Hami melon (*Cucumis melo* var. *reticulatus* Hami melon) variety planted in large areas in Xinjiang Uyghur Autonomous Region of China for both the foreign and local markets. It has an elongated oval shape, reticulated rind, deep uniform green skin, and orange flesh; owing to its favorable quality benefiting from the uniquely advantageous desert climate, including plump, crisp, juicy, and sweet flesh, high nutritional quality, and agreeable aroma, Jiashi melon is popular with customers.[1]

Aroma is one of the most important quality criteria of fruits and vegetables in influencing consumer preferences.[2] Therefore, studies of the volatile compounds in Hami melon have been undertaken.[3−6] However, few systematic studies have been made to identify its aroma-active compounds.[7] To fill this gap, the potent odorants of Jiashi muskmelon juice were recently characterized using gas chromatography–olfactometry/detection frequency analysis (GC-O/DFA) and odor activity value (OAV) calculation, respectively.[8] In this study, (2E,6Z)-nona-2,6-dienal and ethyl butanoate were revealed as the two most important aroma contributors to Jiashi muskmelon juice. In addition, both OAV and DFA showed that branched esters as well as alcohols and aldehydes with nine carbon atoms played a key role in Jiashi melon aroma profile. On the other hand, there were also differences between aroma compound profiles obtained from DFA and OAV. Thus, these differences raised the following question: which method, DFA or OAV, is superior in potent odorant identification for the given food matrix, Jiashi muskmelon juice? The preparation of an aroma model by using the natural concentrations of the single odorants based on GC-O/DFA and

OAV analytical data is the only available method to confirm whether their analytical results have led to the original blueprint of Jiashi muskmelon aroma.[9]

In addition, during OAV calculation and GC-O analysis, the odor impact of a volatile was evaluated after separation by GC, whereas the aroma profile of a product is imparted by an odor mixture. Many investigations[10−14] have suggested that odor mixtures sometimes provide perceptual cues that single compounds lack and that odor mixtures are not always simple sums of their components due to perceptual interactions of odorants such as suppression, synergism, and antagonism. Therefore, there is another point to be further verified: are those compounds identified by both OAV and DFA as odorants actual aroma contributors to Jiashi muskmelon juice? For this question, omission tests provided an effective solution because they could provide definitive evidence of one compound's importance in the overall aroma of a product by studying the effect that the elimination of this compound from the model had on its original sensory characteristics.[15] Recently, recombination experiments and omission tests have been widely used to verify and rank the aroma contribution of individual aroma compounds in many products.[7,9,15−20]

The aims of the present study were (i) to prepare an aroma model matrix based on measurement of main nonvolatile compounds of Jiashi muskmelon juice, (ii) to re-engineer aroma models based on analytical data from DFA and OAV and to compare their effectiveness in Jiashi melon's aroma profile

Table 1. Volatile Pattern and Aroma Profile of Jiashi Muskmelon Juice Obtained from Gas Chromatography–Mass Spectrometry (GC-MS), Odor Activity Value (OAV), and Detection Frequency Analysis (DFA)

no.[a]	compound[b]	CAS Registry No.	concn[c] (ng/mL)	OAV[d]	DF[e]	no.[a]	compound[b]	CAS Registry No.	concn[c] (ng/mL)	OAV[d]	DF[e]
1	methyl acetate	79-20-9	158			25	2,2,6-trimethylcyclohexan-1-one	62861-88-5	0.38		
2	ethyl acetate	141-78-6	1.10e3	220		26	2-phenylacetaldehyde	122-78-1	3.32		3
3	ethyl propanoate	105-37-3	361	36.1		27	3,5,5-trimethylcyclohex-2-en-1-one	78-59-1	11.4		3
4	2-methylbutan-1-ol	34713-94-5	45.7			28	3-acetyloxybutan-2-yl acetate	1114-92-7	4.40		
5	ethyl 2-methylpropanoate[f]	97-62-1	94.0	940	8	29	2-butoxyethyl acetate	112-07-2	2.55		
6	2-methylpropyl acetate[f]	110-19-0	67.0	1.02	2	30	(Z)-non-6-enal[g]	2277-19-2	9.16	458	8
7	methyl 2-methylbutanoate[f]	868-57-5	25.6	10.2	3	31	nonanal[g]	75718-12-6	4.36	4.36	5
8	diethyl carbonate	105-58-8	5.26			32	(2E,6Z)-nona-2,6-dienal[g]	557-48-2	327	3.27e4	8
9	hexanal	9012-63-9	17.8	3.96	2	33	(3Z,6Z)-nona-3,6-dien-1-ol[g]	56805-23-3	201	2.01e4	8
10	ethyl butanoate[f]	105-54-4	3.85e3	3.85e3	8	34	(E)-2-nonenal[g]	30551-15-6	10.1	126	8
11	butyl acetate	123-86-4	117	1.77		35	phenylmethyl acetate	140-11-4	1.99		
12	ethyl 2-methylbutanoate[f]	7452-79-1	115	1.15e3	8	36	nonan-1-ol	28473-21-4	1.84		
13	(E)-hex-2-enal	73543-95-0	31.2	1.84		37	5-methyl-2-propan-2-ylcyclohexan-1-ol	89-78-1	0.91		
14	hexan-1-ol	25917-35-5	4.44			38	decanal	75718-12-6	1.56	15.6	
15	3-methylbutyl acetate	29732-50-1	14.3	7.15		39	2-(4-methylcyclohex-3-en-1-yl)propan-2-ol	98-55-5	0.38		2
16	2-methylbutyl acetate	624-41-9	38.8	7.76		40	2,6,6-trimethylcyclohexene-1-carbaldehyde	52844-21-0	2.15		6
17	heptanal	85-86-9	283	94.3	7	41	(5E)-6,10-dimethylundeca-5,9-dien-2-one	689-67-8	0.54		
18	benzaldehyde	317-34-0	13.1		2	42	(E)-4-(2,6,6-trimethylcyclohex-2-en-1-yl)but-3-en-2-one	127-41-3	0.21	30.0	
19	oct-1-en-3-ol	57-71-6	0.54		8						
20	6-methylhept-5-en-2-one	409-02-9	3.22		5						
21	octanal	823-40-5	1.02								
22	(Z)-hex-3-enyl acetate	3681-71-8	0.29								
23	hexyl acetate	88230-35-7	1.65		4						
24	2-ethylhexan-1-ol	704-76-7	9.02								

[a]Compounds are shown according to their order appearance in the chromatogram on DB-5 column. [b]Volatiles were identified by comparing their linear retention indices (LRI) and MS fragmented patterns with those of standard compounds and published data (acceptable variability of the retention index between the calculated and one from reference was <20), as well as by comparing their mass spectra with the MS library of NIST08. [c]Concentration was expressed in nanograms per milliliter of juice, and the data listed are the mean of three assays. [d]Potential aroma-active compounds characterized by OAV calculation due to their OAV ≥1. [e]Potent odorant indentified by GC-O/DFA according to an arbitrary criterion of total detection frequency ≥2. [f]Aroma-active esters identified by both DFA and OAV. [g]Odor-impact aldehydes and alcohols with nine carbon atoms characterized by both DFA and OAV.

characterization, and finally (iii) to verify the importance of previously identified odorants using omission tests.

■ MATERIALS AND METHODS

Chemicals. All reference standards for aroma model recombination in Table 1 were purchased from Sigma-Aldrich, Milwaukee, WI, USA (no. 1, 3–6, 10, 11, 13, 14, 17, 18, 20, 21, 23, 30, 32, 35, 36, 38–40), J&K Chemical Ltd., Beijing, China (no. 2, 7, 9, 12, 16, 19, 24–26, 29, 31, 34, 37, 41, 42), and Shanghai Oriental Limited Epristeride, Shanghai, China (no. 8, 15, 22, 27–29, 33). Ethanol (HPLC grade) for dissolving reference standards was from J&K Chemical Ltd., Beijing, China. Sugars (chromatographic grade) and organic acids (analytical pure) used for odorless juice model matrix development were purchased from Supelco Co. (Bellefonte, PA, USA) and Sigma-Aldrich,respectively. Ultrapure water used as solvent of the model matrix was prepared with a 2000D ultrapure water implement (Changfeng Instrumentation Co., China). Other reagents were purchased from Beijing Chemical Reagent Co., China.

Melon Samples and Juice Preparation. One late-maturing kind of Jiashi muskmelon (group Hami melon var. *zard*) grown in Xinjiang Uyghur Autonomous Region of China was used, considering it has a relatively long (>6 months) shelf life and is suitable for long-distance transportation.[21] Harvesting was executed in late August using a combination of different harvest indices, including about three-fourths firm and dry skin netting development, aroma emission detected by the human nose, dark green skin color, development of an annular ring in the peduncle, and peduncle suberization.[8] After harvest and pre-cooling in a domestic refrigerator (4 °C) for 24 h, the fruits were transported by air to China Agricultural University. To avoid aroma changes during after-ripening, melons were cut into pieces, fully mixed,

and frozen according to the method of Ma,[5] which has been proved to be able to maintain the original melon overall aroma. Then, melon pieces were immediately vacuum-sealed in aluminum foil compound bags (20 × 15 cm²) and stored at −18 °C. Two randomly selected bags of melon pieces were juiced according to the method of Chen[6] for each analysis, and each analysis was carried out in triplicate.

Analysis of Sugars and Organic Acids in Jiashi Muskmelon Juice. The release of odorants in the food matrix varied greatly with its nonvolatile compositions.[22] Thus, to sufficiently imitate the original food matrix, main nonvolatiles in the original product must be taken into account. Sugars and organic acids were reported as the two main nonvolatiles of melon fruits besides water that could affect human perception of melon aroma.[23,24] Therefore, to simulate exactly original Jiashi melon juice matrix, sugars and organic acids were measured.

High-performance liquid chromatography (HPLC) analysis as well as an external standard method was used for sugar and organic acid measurement according to the methods of Wang et al.[25] and Gao et al.,[26] respectively. The juice sample used for HPLC analysis was prepared following the method of Obando-Ulloa et al.[23] with some modifications. A mixture of melon juice and distilled water (1:2 by volume) was first heated at 50 °C for 30 min and then centrifuged in a refrigerated centrifuge (Neofuge15R, Shanghai Lishen Science Apparatus Co., China) at 9000 rpm for 15 min at 4 °C. Afterward, the supernatant was collected for HPLC analysis after filtration through Millipore membranes (pore size = 0.45 μm).

Aroma Model Reconstitutes. It is a well-known phenomenon that the overall aroma of a mixture of odor-active compounds cannot be predicted.[9] Therefore, to verify the obtained data from DFA and OAV and compare their effectiveness in characterization of Jiashi muskmelon aroma, aroma recombinates were prepared and then compared

with the original muskmelon juice aroma according to the procedure of Steinhaus et al.[9] A water solution containing the identified sugars and organic acid in the concentrations naturally occurring in original melon juice was prepared as the aroma model matrix. Three aroma synthetic solutions were prepared as follows: aroma recombination model 1 included 42 volatiles identified by GC-MS; aroma reconstitute model 2 included 21 odorants with OAVs ≥1, whereas aroma recombinate 3 contained 20 compounds with DF (the total detection frequencies for an odor with the same retention index and a similar description during eight GC-O runs) ≥2 (Table 1). Compounds included in three aroma recombination models were all in their natural concentrations as shown in Table 1.

Electronic Nose Analysis. A GC flash electronic nose (EN, Alpha MOS Heracles, France) was used to tentatively estimate the aroma profile similarity between three reconstitute models and the original melon juice, considering that it is powerful for providing an odor print of the sample by mimicking the human olfactory perception.[27] The procedures are as follows: 2 mL of each aroma synthetic solution and the original juice were prepared in septum-sealed screw cap bottles and equilibrated for 300 s at 40 °C. Afterward, aroma headspace was introduced into the electronic nose at a speed of 270 μL/s. The column temperature program was 40 °C (1 min) raised at 2 °C/min to 200 °C, and then held for 3 min). The temperatures of the injector and detector were set at 180 and 220 °C, respectively. Each sample was tested in triplicate.

Sensory Evaluation. Sensory evaluations were conducted for further investigation of concrete sensory differences between each aroma model and the original juice. A penal of 10 judges (6 females and 4 males aged between 20 and 35 years), recruited from the National Engineering Research Center for Fruits and Vegetables Processing, China, was used. Considering that a single sensory attribute cannot sufficiently reflect contributions of all components to the aroma of a mixture,[28] five aroma descriptors as well as their corresponding chemical markers (aroma standard references that were dissolved in the juice model matrix composed by sugars and organic acids at a concentration 100-fold above the respective odor threshold), namely, fruity (ethyl 2-methylbutanoate), cantaloupe-like ((Z)-6-nonenal), floral (6-methyl-5-hepten-2-one), cucumber-like ((2E,6Z)-nona-2,6-dienal), and green (hexanal), were selected on the basis of related reference and after consensus among the panelists in the first session.[29−31] Then, aroma synthetic solutions and the original muskmelon juice coded with three-digit codes in a random order were served (using tawny glass bottles to mask color differences), and QDA was carried out in a sensory panel room (21 ± 1 °C; artificial light was used to mask different colors of models and, therefore, to prevent bias) by asking assessors to rate each selected odor quality using a seven-point linear intensity scale of 0, 0.5, 1.0, 1.5, ..., 3.0 as reported by Chetschik et al.[19] The sensory evaluations of each sample were carried out in triplicate. The results obtained at three different sessions were averaged for each odor note and plotted in a spider web diagram.

Omission Test. Altogether, six aroma omission models were prepared. The first three were prepared to verify the aroma contribution of five unsaturated C_9 aldehydes and alcohols as well as five branched esters that were identified as potent odorants of Jiashi muskmelon by both GC-O/DFA and OAV from the complete model (model including 42 volatiles identified by GC-MS) as follows: model 1, omitting five C_9 aldehydes and alcohols as well as five odor-active esters listed in Table 1; model 2, omitting five aroma-active esters; and model 3, omitting five potent unsaturated C_9 aldehydes and alcohols.

To corroborate the contributions of ethyl butanoate and (2E,6Z)-nona-2,6-dienal that were identified as the two most potent odorants of Jiashi muskmelon, another three omission models, omission models 4 (omitting both ethyl butanoate and (2E,6Z)-nona-2,6-dienal), 5 (omitting (2E,6Z)-nona-2,6-dienal), and 6 (omitting ethyl butanoate) were developed on the basis of the complete model. Then, these omission models were compared with the original melon juice using QDA, and the comparative results were then presented in a spider web diagram as described for reconstitution experiments. Again, in a separate session, the overall similarity between the complete model and the

omission models was evaluated using a nine-point linear scale from 1, being extremely different, to 9, being extremely similar, as suggested by Dharmawan et al.[32]

Statistical Analysis. QDA results were conducted with ANOVA using OriginPro v8.0 (OriginLab Inc., Northampton, MA, USA) and were considered to be significantly different at $P < 0.05$. Then, a Tukey test was used to find significant differences between different models in each aroma quality as well as in their overall aroma. Principal component analysis (PCA) (AlphaSoft v.11, Toulouse, France) was used to extract important information from abundant ENA raw data of peak area for each sample to evaluate the aroma profile similarity between three reconstitute models and the original juice. In addition, the distance between the data clusters for the each aroma model and the original melon juice in the PCA plot was determined to assess their odor profile similarity following the method of Tokuyama et al.[33]

RESULTS AND DISCUSSION

Sugar and Organic Acid Profiles. The main soluble sugars identified included fructose, sucrose, and glucose. Sucrose had the highest content (36.71 mg/mL), 2.14 and 2.41 times as much as that of glucose (17.19 mg/mL) and fructose (15.24 mg/mL), respectively. This result was in accordance with Obando-Ulloa,[23] who characterized sucrose and glucose as the major sugars in Spanish cultivar Piel de Sapo melon.

Six organic acids, namely, malic acid, oxalic acid, Vc, citric acid, succinic acid, and fumaric acid were identified in Jiashi muskmelon juice, and their contents ranged greatly. L-Malic acid had the highest content (2691.60 mg/mL), followed by citric acid (323.34 mg/mL), succinic acid (290.22 mg/mL), D-malic acid (265.71 mg/mL), Vc (50.51 mg/mL), oxalic acid (8.05 mg/mL), and fumaric acid (0.51 mg/mL). Malic acid, succinic acid, and citric acid were previously identified as three main organic acids in melon cultivars belonging to *C. melo* L. *reticulatis* group.[34] It is worth noting that D-malic acid was detected in this study, even though it was reported that only L-malic acid occurred naturally, whereas D-malic acid was found in appreciable concentration only in the metabolism of some micro-organisms. Considering that freezing could change the chemical composition of fruits,[35] we supposed the detection of D-malic acid might result from the freezing treatment of melon pieces. However, this needs to be verified in further research.

Aroma Reconstitution Experiments. PCA results showed that the first two principal components accounted for 97.2% of total variance (Figure 1), indicating the ENA distinguished easily the different aroma reconstitute models. As revealed in Figure 1, the aroma profile of re-engineered model derived from OAV (model 2) resembled that of the model based on GC-MS analysis (model 1), indicating that OAV calculation did appropriately sort out odorants that most likely do not contribute to the overall aroma of Jiashi muskmelon juice.

It has been shown that the smaller the Euclidean distance between two samples, the more similar their aroma.[33] As shown in Figure 1, model 1 was the closest to the original juice (3327), followed by the OAV-based model (3568), whereas the DFA-based model was the furthest one (5280). This result tentatively indicated that compared with GC-O/DFA, OAV was more effective in the characterization of Jiashi muskmelon aroma profile.

Sensory differences between each aroma model and the original juice were further compared using QDA. As for the five aroma properties of Jiashi muskmelon juice, the "cantaloupe-like" note was rated with the highest score, followed by "cucumber-like", "fruity", "floral", and "green" (Figure 2). As in
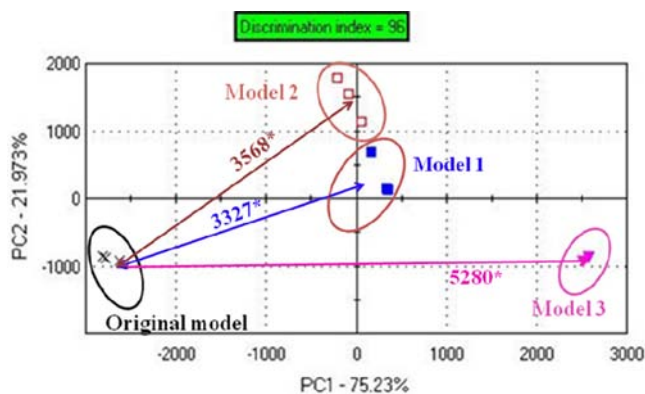
Figure 1. PCA plots of electronic nose data for the original Jiashi muskmelon juice and different aroma synthetic solutions based on data from gas chromatography—mass spectrometry (GC-MS), odor activity value (OAV), and gas chromatography—olfactometry/detection frequency analysis (GC-O/DFA) as well as Euclidean distance between each aroma recombination model and the original model.
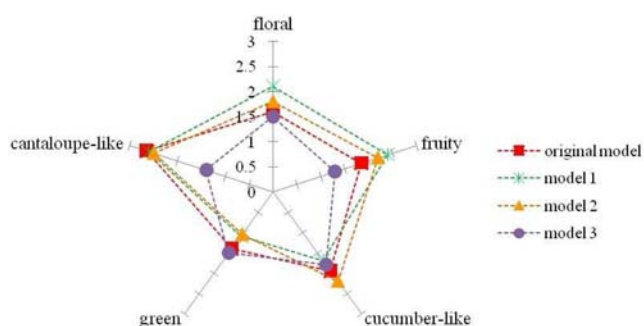

Figure 2. Sensory evaluation of Jiashi muskmelon juice and aroma re-engineering models based on data from gas chromatography—mass spectrometry (GC-MS), odor activity value (OAV), and gas chromatography—olfactometry/detection frequency analysis (GC-O/DFA).

the case of Jiashi muskmelon, "melon-like" and "fruity" qualities were characterized as the two most important aroma notes of *C. melo* var. *inodorus* by Verzera et al.[29] In addition, yellow-fleshed and thin-skinned Black melon (*C. melo* var. *inodorus*) was reported to score highest for "cucumber-like" note,[36] whereas "floral" and "green" were rated highest for orange-fleshed cantaloupe (*C. melo* var. *cantalupensis* Naud.) and honeydew (*C. melo* var. *inodorus* Naud.), respectively.[30] This suggested that different melon cultivars varied greatly in their aroma profiles.

As for aroma profiles of three aroma models, "floral" and "fruity" were rated slightly higher in model 1 than in the original muskmelon juice, whereas "cantaloupe-like", "cucumber-like", and "green" were rated slightly lower (Figure 2). However, there was no significant difference ($P < 0.05$) between all odor attributes of these two models, indicating that the Jiashi muskmelon aroma model was successfully recombined.

As to model 2 (OAV-based model), intensities of "floral", "fruity", and "cucumber-like" were rated slightly higher than in the original juice, whereas the "green" and "cantaloupe-like" notes were just the opposite (Figure 2). However, no significant difference was observed in the five aroma notes between these two solutions, revealing that the aroma model based on OAV had a high similarity with the original juice. In other words, OAV is an effective method for potent odorant characterization of Jiashi muskmelon.

With respect to model 3 (DFA-based model), "cantaloupe-like" was rated significantly lower than in the original juice (Figure 2), leading to the conclusion that GC-O/DFA was not as reliable as OAV calculation with regard to odor-active compound identification of Jiashi muskmelon juice.

The above analysis showed that ENA tallied with QDA, and both of them proved that OAV is a more effective method in Jiashi muskmelon's potent odorant characterization compared with DFA. This result was in accordance with previous findings that OAV short-listed effectively potent odorants, whereas DFA might not always correlate directly to the aroma-active compounds in food.[16,32,37−39] Meanwhile, this result indicated that ENA might take the place of conventional sensory evaluation as a potential tool to evaluate the effectiveness of different identification methods for aroma-active compounds of melon fruits. However, EN also has limitations, such as signals that are highly correlated and could not differentiate between "top" and "middle" notes of an aroma.[40] In addition, only one melon cultivar with uniform maturity degree was used in this study. Thus, the possibility of EN taking the place sensory evaluation needs to be further verified using more melon cultivars with different maturity degrees from different seasons.

Omission Test. Compared with the virtual melon juice, significant differences were observed in the average score of ratings in omission model solutions 1, 2, and 3 (Table 2), suggest-

Table 2. Sensory Evaluation for the Complete Aroma Model of the Jiashi Muskmelon Juice As Affected by the Omission of Compounds

aroma model	compound(s) omitted	av score[a]
complete model	none (Jiashi muskmelon juice aroma model based on data from gas chromatography—mass spectrometry listed in Table 1)	7.6 ± 0.49a
omission model 1	five odor-impact unsaturated aldehydes and alcohols with nine carbon atoms as well as five potential aroma-active esters shown in Table 1	4.2 ± 0.36e
omission model 2	five potential aroma-active esters listed in Table 1	5.2 ± 0.61d
omission model 3	five odor-impact C_9 aldehydes and alcohols listed in Table 1	6.0 ± 0.66bc
omission model 4	ethyl butanoate and (2E,6Z)-nona-2,6-dienal	4.8 ± 0.51de
omission model 5	(2E,6Z)-nona-2,6-dienal	6.2 ± 0.36b
omission model 6	ethyl butanoate	5.4 ± 0.46cd

[a]The average score of the intensity was the average score of 10 panelists at three different sessions with a scale of 1 (extremely different from) to 9 (extremely similar to) original Jiashi muskmelon juice. The difference between levels with the same letter is not significant ($P < 0.05$).

ing that unsaturated aldehydes and alcohols with nine carbon atoms as well as branched esters dominated by acetate propyl and butyl esters did play a key role in Jiashi muskmelon odor pattern.

QDA showed that, compared with the complete model, omission models 1 and 2 were rated significantly lower in "floral", "fruity", and "cantaloupe-like" notes, whereas no significant difference was observed in omission model 3 in the above three aroma descriptors (Figure 3). The above results revealed that the five esters including ethyl 2-methylpropanoate, 2-methylpropyl acetate, methyl 2-methylbutanoate, ethyl butanoate, and ethyl 2-methylbutanoate did contribute to "floral", "fruity", and "cantaloupe-like" notes of Jiashi muskmelon. With respect to the "cucumber-like" property, omission models 1 and 3 were rated significantly lower than the complete model. However, there was
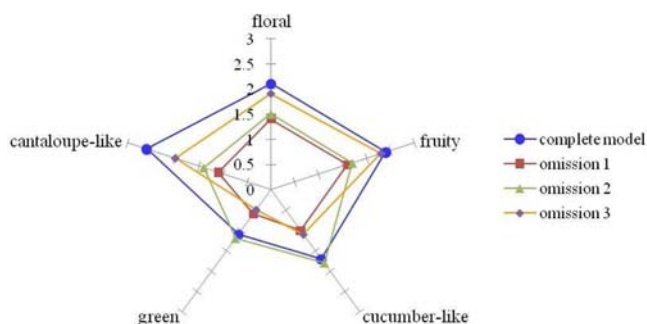
Figure 3. Quantitative descriptive analysis of original Jiashi muskmelon juice and different odor models omitting group of five branched esters and five C_9 aldehydes and alcohols.

no significant difference when only esters were missing (Figure 3). This suggested that five C_9 aldehydes and alcohols, namely (2E,6Z)-nona-2,6-dienal, (3Z,6Z)-nona-3,6-dien-1-ol, (E)-2-nonenal, (Z)-non-6-enal, and nonanal, played a key role in the "cucumber-like" note of Jiashi muskmelon juice. All of these findings agreed well with the conclusion drawn by Kemp[41] that aldehydes and alcohols with nine carbon atoms played a key role in the "melon-like" note of muskmelon. As for the "green" note, the complete model was rated significantly higher than omission models 1 and 3, whereas no significant difference was observed in the omission model missing only esters (Figure 3), indicating that some components among these five C_9 aldehydes and alcohols contributed to the "green" note.

As shown in Table 2, both individual (omission models 5 and 6) and binary omissions (omission model 4) of ethyl butanoate and (2E,6Z)-nona-2,6-dienal resulted in significant difference ($P < 0.05$) in relation to the complete model mixture, suggesting the significant contribution of ethyl butanoate and (2E,6Z)-nona-2,6-dienal to the aroma profile of Jiashi muskmelon juice.

QDA results (Figure 4) revealed that there was no significant "floral" note when one or both of these two components were
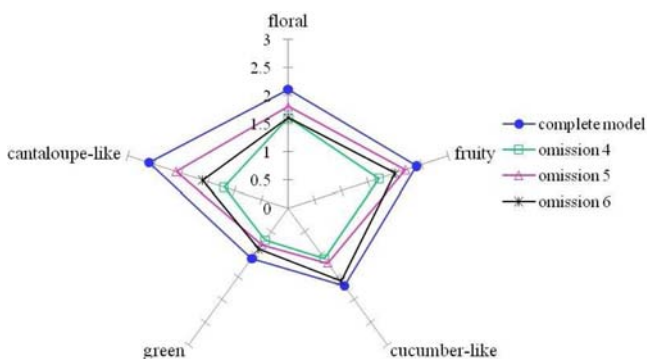

Figure 4. Comparative aroma profile analysis of original Jiashi muskmelon juice and different odor models omitting individual or binary ethyl butanoate and (2E,6Z)-nona-2,6-dienal.

omitted. As for "fruity", no clear difference was observed when either of these two odorants was missing. However, when both compounds are removed (omission model 4), the "fruity" intensity clearly decreased, suggesting that a synergic action of ethyl butanoate and (2E,6Z)-nona-2,6-dienal played a key role in the "fruity" note. With respect to the "cucumber-like" note, omission models 4 and 5 were both rated significantly lower

than the complete model, whereas no significant sensory effect of the individual omission of ethyl butanoate was noted. This result demonstrated that (2E,6Z)-nona-2,6-dienal was a key contributor to the "cucumber-like" property. This was consistent with the finding[42] that (2E,6Z)-nona-2,6-dienal was recognized as the character-impact compound of cucumber. No significant sensory effect on "green" odor was noted with individual or binary omission of ethyl butanoate and (2E,6Z)-nona-2,6-dienal (Figure 4), revealing that neither of them contributed to the "green" note. There was a significant decrease in the score of the "cantaloupe-like" aroma of omission models 4 and 6, whereas no significant reduction was observed when only (2E,6Z)-nona-2,6-dienal was omitted (Figure 4), indicating that ethyl butanoate made a great contribution to the "cantaloupe-like" note. In accordance with our conclusion, ethyl butanoate has been reported as an important aroma contributor to 'Vedrantais' melon cultivar and the Korean cultivar, 'Shongwhan Charmi' melon.[43]

To sum up, aroma reconstitute experiments and omission tests were successfully used in this study to corroborate the contribution of five unsaturated aldehydes and alcohols with nine carbon atoms as well as five branched esters to each aroma property of the Jiashi muskmelon based on the previously obtained data on aroma-active compounds. However, there are some limitations in this study. One thing is that the aroma model matrix used in this study was simplified. Only two main nonvolatile factors (sugars and organic acids) that could affect the perception of odorants were taken into account. As a result, the omission of other nonvolatiles, such as fat and polysaccharides (pectin, hemicellulose, and cellulose) that could more or less influence the perception of odorant either through different types of interaction or changes in juice viscosity,[22,44] might result in a weaker binding between model matrix and odorants compared with the original juice matrix. Thus, to improve the accuracy of the aroma recombination experiment, future emphasis should be on investigating interactions between other nonvolatiles and potent odorants, developing an aroma model matrix that more exactly resembles the original juice matrix, and conducting more omission tests to investigate the interactions between odorants.

■ AUTHOR INFORMATION

Corresponding Author
*Phone/fax: +86-010-62737434-603. E-mail: wjhcau@yahoo.com.cn.

Notes
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