Volatile profiling of fruits of 17 mango cultivars by HS-SPME-GC/MS combined with principal component analysis

Kosuke Shimizu,1 Tetsuya Matsukawa,1,2,∗ Risa Kanematsu,2 Kimihisa Itoh,1 Shinya Kanzaki,1,3 Shigeru Shigeoka,1 and Shin’ichiro Kajiyama2

1Experimental Farm, Kindai University, Wakayama, Japan; 2Department of Biotechnological Science, Faculty of Biology-Oriented Science and Technology, Kindai University, Kinokawa City, Wakayama, Japan; and 3Graduate School of Agriculture, Kindai University, Nara, Japan

∗Correspondence: Tetsuya Matsukawa, tmatsu@waka.kindai.ac.jp

ABSTRACT

Headspace solid-phase microextraction combined with gas chromatography/mass spectrometry is one of the strongest tools for comprehensive analysis of volatile compounds and has been used to analyze aromatic components of mango and investigate its varietal characteristics. In this study, profiling of aroma compounds in 17 mango cultivars, grown in the same green house to exclude the effect of environmental factors, was conducted and the patterns were subjected to principal component analysis (PCA) to identify the relationship between the aroma components and cultivars. Fifty-nine different volatile constituents were detected from the blends of these 17 mango cultivars. The cultivars were divided into 4 clusters using PCA based on the volatile components determined in the study. Aiko was found to mainly contain δ-3-carene and showed a composition more similar to its pollen parent, Irwin, than to its seed parent, Chiin Hwang No. 1.

Graphical Abstract

Volatile composition of fruit of 17 mango cultivars was divided into 4 clusters by HS-SPME GC/MS combined with principal component analysis.

Keywords: Aiko, gas chromatography-mass spectrometry (GC-MS), mango cultivars, Mangifera indica, solid-phase microextraction (SPME)
The fruit of *Mangifera indica* L. (mango) is considered “the king of fruits,” being the most popular fruit in the tropical regions (Lauricella et al. 2017). The genus *Mangifera* includes numerous species of tropical plants in Anacardiaceae (Scartezzini and Speroni 2000). Mango is native to India and Southeast Asia where it has been cultivated for at least 4000 years and over 1000 cultivars are recognized (Mukherjee 1953). It is now also grown in Central America, Africa, Asia, and Australia, and since the last few years in Europe. In some countries, this plant species has a symbolic value—mango is the national fruit of India and the Philippines, and *M. indica* is the national tree of Bangladesh (Usman, Fatima and Jaskani 2001).

Although more than 100 mango cultivars are available worldwide, only a few are grown at a commercial scale. In the late 19th and early 20th centuries, Florida became a secondary center of mango cultivation and contributed to the generation of new cultivars. The mango tree is now the most popular garden tree in this state. The cultivation and breeding of mango plants has also been conducted in Japan. A notable cultivar Aiko, grown at our experimental farm, is the result of interbreeding between the Taiwanese cultivar, Chiin Hwang No. 1 (Ueda et al. 2001), and the mainstay domestic cultivar, Irwin. Breeding and cultivation test for Aiko started in 1999 at our experimental farm and it was registered in 2008 as the first new mango cultivar in Japan (Sasakii et al. 2008).

To establish systematic breeding methods, knowledge about the fruit quality traits, such as fruit size, sugar and acid content, and aroma, is imperative. However, there have been few reports on the relationship between cultivars and their fruit aromas. Previous research in India (Idsteom and Schreier 1985), the USA. (Munafo et al. 2014), Australia (San et al. 2017), Thailand (Tamura et al. 2001), and China (Liu et al. 2013) has focused on the aroma properties of mango cultivars; however, there are only a few systematic reports focusing on the characteristics of intercontinentally cultivated varieties. Breeding based on chemical analysis data of aroma components that contribute to the “taste” of mangoes has not been successful. Aroma components are usually highly complex. A problem associated with their analysis is the low concentration in samples. Moreover, there are no suitable solvents for classical distillation and solvent extraction of water-rich fruit materials.

Headspace solid-phase microextraction combined with gas chromatography/mass spectrometry (HS-SPME-GC/MS) is one of the strongest tools for comprehensive analysis of volatile compounds. It has been used in apple (Apriya et al. 2012), bayberry (Cheng et al. 2015), and mango (San et al. 2017) to analyze aromatic components and to investigate varietal characteristics. There are several difficulties associated with the evaluation of fruit aromas in mango plants. Mango flavor vary by cultivars (Pandit et al. 2009), and they change depending on the processing state and texture (Bonneau et al. 2018). In addition, the aroma components depend on the region in which the plant is grown, being affected by environmental components, such as climate and soil (Kulkarni et al. 2012). In this study, profiling of aroma compounds in 17 mango cultivars was conducted and the patterns were subjected to principal component analysis (PCA) to decipher the relationship of the aroma components and cultivars. The plants were grown in the same greenhouse to exclude the effect of environmental factors. The phylogeny of mango has been genetically studied, and there have been reports on the classification of varieties using SSR markers (Ravishankar et al. 2011); however, the phylogeny of many of the parents of mango cultivars has not been elucidated. To evaluate the inheritance of fruit aroma in mango, a comparison of Aiko and its parents, Chin Hwang No. 1 and Irwin, is also presented in this study.

### Materials and methods

**Chemicals**

Butyric acid and cis/trans-ocimene solution were purchased from Nacalai Tesque (Kyoto, Japan) and Sigma and Aldrich (MO, USA), respectively. All other standards were obtained from Tokyo Chemical Industry (Tokyo, Japan).

**Plant materials**

The ripening mango fruits of 17 cultivars of *M. indica* (cultivars in alphabetical order, Aiko, Alphonso, Chiin Hwang No. 1, etc.) are listed in Table 1. The mango tree is now the most popular garden tree in this state. The cultivation and breeding of mango plants has also been conducted in Japan. A notable cultivar Aiko, grown at our experimental farm, is the result of interbreeding between the Taiwanese cultivar, Chiin Hwang No. 1 (Ueda et al. 2001), and the mainstay domestic cultivar, Irwin. Breeding and cultivation test for Aiko started in 1999 at our experimental farm and it was registered in 2008 as the first new mango cultivar in Japan (Sasakii et al. 2008).

**Table 1. Material seventeen mango cultivars**

<table>
<thead>
<tr>
<th>Cultivar number</th>
<th>Cultivar name</th>
<th>Origin</th>
<th>Embryo mono or poly</th>
<th>Candidate parent (seed)*</th>
<th>Candidate parent (pollen)*</th>
<th>Group in Figure 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aiko</td>
<td>Japan</td>
<td>M</td>
<td>Chinn Hwang No. 1</td>
<td>Irwin</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Alphonso</td>
<td>India</td>
<td>M</td>
<td>White</td>
<td>Unknown</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Chiin Hwang No. 1</td>
<td>Taiwan</td>
<td>M</td>
<td>Haden</td>
<td>Unknown</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Edward</td>
<td>USA</td>
<td>M</td>
<td>Haden</td>
<td>Unknown</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Florigon</td>
<td>USA</td>
<td>P</td>
<td>Haden</td>
<td>Unknown</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Glenn</td>
<td>USA</td>
<td>M</td>
<td>Lippens</td>
<td>Unknown</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Irwin</td>
<td>USA</td>
<td>M</td>
<td>Brooks</td>
<td>Unknown</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>Kent</td>
<td>USA</td>
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<td>Haden</td>
<td>Unknown</td>
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<tr>
<td>9</td>
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<td>Thailand</td>
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<td>Haden</td>
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<td>M</td>
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</tr>
<tr>
<td>11</td>
<td>Maha Chanook</td>
<td>Thailand</td>
<td>P</td>
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<td>Unknown</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>Nam Doc Mai</td>
<td>Thailand</td>
<td>P</td>
<td>Keitt</td>
<td>Yu-Win No.6</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Hong Long</td>
<td>Taiwan</td>
<td>M</td>
<td>Irwin</td>
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</tr>
<tr>
<td>14</td>
<td>Red Keitt</td>
<td>Taiwan</td>
<td>M</td>
<td>Brooks</td>
<td>Haden</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>Sensation</td>
<td>USA</td>
<td>M</td>
<td>Zill</td>
<td>Haden</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>Spirit of 76</td>
<td>USA</td>
<td>M</td>
<td>Haden</td>
<td>Unknown</td>
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</table>

*Parentage was described in literatures of Yamanaka et al. (2019).*
Table 2. Volatile compounds in fruits of seventeen mango cultivars

<table>
<thead>
<tr>
<th>Peak ID</th>
<th>Category</th>
<th>Compound name</th>
<th>Retention indices (RI)</th>
<th>RI in literature</th>
<th>Similarity indices</th>
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<tr>
<td>1</td>
<td>Acid</td>
<td>Butyric acid</td>
<td>802</td>
<td>CC</td>
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</tr>
<tr>
<td>2</td>
<td>Acid-like</td>
<td></td>
<td>816</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>Lactone-like</td>
<td></td>
<td>847</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Monoterpene</td>
<td>α-Pinene</td>
<td>928</td>
<td>CC</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Monoterpene-like 1</td>
<td>Camphene</td>
<td>931</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Monoterpene</td>
<td>β-Pinene</td>
<td>959</td>
<td>943b</td>
<td>90</td>
</tr>
<tr>
<td>7</td>
<td>Monoterpene</td>
<td>γ-Phallandrene</td>
<td>967</td>
<td>969b</td>
<td>90</td>
</tr>
<tr>
<td>8</td>
<td>Monoterpene</td>
<td>Monoterpene-like 2</td>
<td>1002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Aldehyde</td>
<td>Octanal</td>
<td>1004</td>
<td>CC</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Monoterpene</td>
<td>α-Phallandrene</td>
<td>1006</td>
<td>CC</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Monoterpene</td>
<td>i-3-Carene</td>
<td>1011</td>
<td>CC</td>
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<tr>
<td>12</td>
<td>Monoterpene</td>
<td>α-Terpinene</td>
<td>1015</td>
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</tr>
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<td>Monoterpene</td>
<td>(E)-Caren-2-ol</td>
<td>1022</td>
<td>1138b</td>
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</tr>
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<td>a-Limonene</td>
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<tr>
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<td>Monoterpene</td>
<td>(Z)-β-Ocimene</td>
<td>1031</td>
<td>CC, 1040e, 1039d</td>
<td>98</td>
</tr>
<tr>
<td>16</td>
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<td>Nonanal (internal standard)</td>
<td>1106</td>
<td>CC</td>
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</tr>
<tr>
<td>17</td>
<td>Aldehyde</td>
<td>2,6-Dimethyl-1,3,5,7-octatetraene</td>
<td>1116</td>
<td>1134f</td>
<td>93</td>
</tr>
<tr>
<td>18</td>
<td>Aliphatic compound</td>
<td>2,4,6-Octatriene</td>
<td>1127</td>
<td>1143f</td>
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</tr>
<tr>
<td>19</td>
<td>Monoterpene</td>
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<td>1040</td>
<td>CC, 1050f, 1050d</td>
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</tr>
<tr>
<td>20</td>
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<td>Monoterpene-like 3</td>
<td>1046</td>
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<td></td>
</tr>
<tr>
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<td>1070</td>
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<td>p-Cymene</td>
<td>1072</td>
<td>CC</td>
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</tr>
<tr>
<td>24</td>
<td>Unidentified</td>
<td>Unidentified (ester-like)</td>
<td>1284</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Aldehyde</td>
<td>Humulene</td>
<td>1473</td>
<td>CC, 1454f, 1442f</td>
<td>96</td>
</tr>
<tr>
<td>26</td>
<td>Sesquiterpene</td>
<td>β-Copaene</td>
<td>1429</td>
<td>1407f, 1408f</td>
<td>90</td>
</tr>
<tr>
<td>27</td>
<td>Sesquiterpene</td>
<td>α-Gurjunene</td>
<td>1440</td>
<td>CC, 1418f, 1420d</td>
<td>96</td>
</tr>
<tr>
<td>28</td>
<td>Sesquiterpene</td>
<td>β-Caryophyllene</td>
<td>1446</td>
<td>1421f</td>
<td>90</td>
</tr>
<tr>
<td>29</td>
<td>Sesquiterpene</td>
<td>a-Guaiene</td>
<td>1453</td>
<td>1439f, 1437f</td>
<td>91</td>
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<tr>
<td>30</td>
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<td>Sesquiterpene-like 1</td>
<td>1465</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>Humulene</td>
<td>1473</td>
<td>CC,1454f, 1442f</td>
<td>96</td>
</tr>
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<td>β-Copaene</td>
<td>1479</td>
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<td>Sesquiterpene</td>
<td>valvesene</td>
<td>1487</td>
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<tr>
<td>34</td>
<td>Sesquiterpene</td>
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<td>1486</td>
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<td>Germacrene-D</td>
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<td>1480f, 1481j</td>
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<tr>
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<td>1504</td>
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<td>37</td>
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<td>Selinene</td>
<td>1512</td>
<td>1484f</td>
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<tr>
<td>38</td>
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<td>Valencene</td>
<td>1516</td>
<td>1491f, 1492f</td>
<td>90</td>
</tr>
<tr>
<td>39</td>
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<td>1519</td>
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<td>40</td>
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<td>δ-Guaiene</td>
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<td>1500f</td>
<td>91</td>
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<td>41</td>
<td>Sesquiterpene</td>
<td>γ-Muurolene</td>
<td>1534</td>
<td>1498f</td>
<td>90</td>
</tr>
</tbody>
</table>
The MS ion source and interface temperatures were 200 °C and
15 °C min
−1.

Continuous agitation at 600 s
−1.

The SPME fiber was inserted into

The volatile components in the fruits of 17 mango cultivars are
detected, 40 of which were annotated or identified based on
comparison of their mass fragmentation patterns to the NIST
library and retention indices in literatures or cochromatography
with authentic standards. Retention indices (RIs) from the literature were used
for identification of volatiles. The threshold of RI differences
was set at ±15 for RI < 1300 and ±40 for RI > 1300 according
to the RI differences in literatures and authentic standards of
(E)-β-ocimene (RI < 1300) and humulene (RI > 1300). The peak
areas of all compounds relative to that of the highest peaks
were used for the multivariate analysis. PCA was performed
using the SIMCA ver. 13.0.3 software (Umetrics, Umeå, Sweden).
Pareto scaling was applied to the data processing before PCA
analysis.

Results

Mango cultivar formation and estimation of volatile components

The volatile components in the fruits of 17 mango cultivars are
shown in Table 2. A total of 59 different volatile constituents
were detected, 40 of which were annotated or identified based on
comparison of their mass fragmentation patterns to the NIST
library and retention indices in literatures or cochromatography
with authentic standards. Seventeen monoterpenes were anno-
tated, among which 13 consisted of the main components of
mango fruit aroma. To assess the differences in monoterpene
patterns in each variety, relative amounts of each annotated
monoterpene were compared (Figure 1). The main components
of Aiko, Edward, Glenn, Irwin, Kent, Lippens, Red Keiit, Sensa-
tion, Spirit of 76, and Valencia Pride were

HP-SPE-GC/MS

The frozen fruits were cut and divided into flesh, peels and
seeds, and peels and seeds were discarded. The flesh was cut
and chopped with knives until well homogenized and a por-
tion (0.5 g) of homogenized flesh was placed in a 20 mL glass
vial. Two milliliters of saturated sodium chloride solution and
10 μL of 10 ppb (w/w) nonanal (an internal standard, Tokyo
Chemical Industry, Tokyo, Japan) in EtOH were added before
capping the vial. We performed GC/MS analyses of all culti-
vars and checked that nonanal was not detected in all sam-
ples, and thus, we selected nonanal as the internal standard.
The GC/MS analysis was performed using a GCMS-QP2010 Ultra
equipped with an AOC-5000 Plus autosampler (Shimadzu, Ky-
oto, Japan). Headspace volatile organic compounds (VOCs) were
extracted using an SPME fiber coated with 50/30 μm of divinyl-
benzene/carboxen/polydimethylsiloxane at 50 °C for 60 s with
continuous agitation at 600 s
−1.

GC/MS data analysis

GC/MS chromatograms were analyzed using the GCMS solution
ver. 4.11 (Shimadzu, Kyoto, Japan). The mass spectra data were
compared against spectra in the NIST reference library (NIST14)
of the GC/MS data system for identification of volatile comp-
ounds. Compounds were annotated under the condition of
processing a similarity index of more than 90, and major com-
ponents were identified by cochromatography with authentic
standards. Retention indices (RIs) from the literature were used
for the identification of volatiles. The threshold of RI differences
was set at ±15 for RI < 1300 and ±40 for RI > 1300 according
to the RI differences in literatures and authentic standards of
(E)-β-ocimene (RI < 1300) and humulene (RI > 1300). The peak
areas of all compounds relative to that of the highest peaks
were used for the multivariate analysis. PCA was performed
using the SIMCA ver. 13.0.3 software (Umetrics, Umeå, Sweden).
Pareto scaling was applied to the data processing before PCA
analysis.

Principal components analysis

To compare the volatile components among cultivars, the peak
patterns (including unidentified peaks) of HS-SPME-GC/MS were
Volatile profiling of 17 mango cultivar fruits

Figure 1. Comparison of the monoterpene composition of fruit in 17 mango cultivars. Cultivar names are represented by 3 letters: Aiko (Aik), Alphonso (Alp), Chinn Hwang No. 1 (Chi), Edward (Edw), Florigion (Flo), Glenn (Gle), Hong Long (Hon), Irwin (Irw), Kent (Ken), Khom (Kho), Lippens (Lip), Maha Chanook (Mah), Nam Doc Mai (Nam), Red Keit (Red), Sensation (Sen), Spirit of 76 (Spi), and Valencia Pride (Val). Different bar patterns correspond to different monoterpenes as shown in the right panel. Group represents the clusters shown in Figure 2.

subjected to PCA (Figure 2). According to the score plot, the 17 cultivars could be clearly divided into 4 groups: Group 1 contained Spirit of 76, Glenn, Valencia Pride, Sensation, Red Keit, Lippens, Edward, Aiko, Kent, and Irwin in the positive region of PC 1 and in the negative region of PC 2. Group 2 consisted of Chinn Hwang No. 1, Maha Chanook, Florigion, and Hong Long in the neutral region of PC 1 and in the positive region of PC 2. Group 3 contained Alphonso and Khom in the negative region of PC 1 and in the neutral region of PC 2 (Figure 2a). Group 4 consisted of only 1 cultivar, Nam Doc Mai. The loading plot showed that δ-3-carene strongly contributed to the clustering in the positive region of PC 1 and in the negative region of PC 2, whereas α-terpinolene significantly affected the clustering to the positive region of PC 2 (Figure 2b). Two sesquiterpenes, humulene and β-caryophyllene, and (E)- and (Z)-β-ocimene contributed to the clustering in the negative region of PC 1. The largest cluster detected in the score plot was Group 1, and the cultivars in this cluster were characterized to have monotonous and refreshing scent, with δ-3-carene as the main compound (Figure 2). The second largest cluster was Group 2, and the cultivars in this cluster contained more α-terpinolene than other cultivars. The Alphonso and Khom clusters contain a lot of β-ocimene, whereas Alphonso mainly contains (Z)-β-ocimene, and the main component of Khom aroma is (E)-β-ocimene (Figure 1). Both the β-ocimene isomers form a characteristic mango odor, and thus, make the difference between these and other cultivars. Nam Doc Mai formed a single cultivar cluster, suggesting that the aroma pattern of this cultivar is different from that of other cultivars tested. Nam Doc Mai had a significantly low amount of δ-3-carene, the common main component in other cultivars, and contained a large amount of β-caryophyllene, a trace sesquiterpene in other cultivars.

Discussion

Monoterpenes are known to account for nearly 90% of the aroma components in the ripe fruit of Alphonso originating in India (Idsteom and Schreier 1985). They are also reported to be the main components in most of the cultivars from Florida (MacLeod and Snyder 1985) and Thailand (Tamura et al. 2001). However, the composition of the components differs depending on the variety. In this study, δ-3-carene was the main component of the Florida cultivars, excluding Florigion, whereas (E)-β-ocimene was the main component in the Indian variety Alphonso. Florigion and 2 Taiwanese cultivars, Chinn Hwang No. 1 and Hong Long, mainly contained α-terpinolene, but also had a lot of δ-3-carene. A part of α-terpinolene is thought to be converted to α-terpineol and terpinene-4-ol during storage (Kitao 1993). Because both the compounds have been reported to cause nonpreferable fishy and plastic odors (Kitao 1993; Elmaci and Altug 2005), storage condition of the fruit of these cultivars should be strictly controlled to avoid the production of α-terpineol and terpinene-4-ol. Alphonso and Khom were classified into the same cluster, but their main components were (Z)-ocimene and (Z)-ocimene, respectively. The basic skeleton of these compounds is the same and they are geometric isomers; both the isomers are biosynthesized via a common pathway, and thus, Alphonso and Khom have a common system for the regulation of monoterpene biosynthesis. Compared to all other cultivars, Nam Doc Mai has a high ratio of limonene and contains various volatile components at relatively higher proportions. Therefore, Nam Doc Mai shows unique fruit aroma. In general, mango cultivars belong to 2 distinct groups, i.e. polyembryonic types and monoembryonic types (Mukherjee 1953). Polyembryonic cultivars such as Nam Doc Mai are common in Asia, and they have been cultivated traditionally.
Figure 2. Principal component analysis (PCA) model of 17 mango cultivars based on HS-SPME-GC/MS analysis. (a) Score plot for principal component 1 (PC1) and PC2 ($R^2_X[1] = 0.280$, $R^2_X[2] = 0.203$), showing different symbols for the different cultivars: Aiko (open circles), Alphonso (closed circles), Chiin Hwang No. 1 (open boxes), Edward (closed boxes), Florigon (open triangles), Glenn (closed triangles), Hong Long (open inverted triangles), Irwin (closed inverted triangles), Kent (open diamonds), Khom (closed diamonds), Lippens (open pentagon), Maha Chanook (closed pentagon), Nam Doc Mai (open hexagon), Red Keiit (closed hexagon), Sensation (open 4-pointed star), Spirit of 76 (closed 4-pointed star), and Valencia Pride (open 5-pointed star). (b) Loading plot for PC1 and PC2. Numbers are peak IDs shown in Table 2.

In polyembryonic mango, each seed contains 1 sexual embryo and several somatic or nu-
cellar ones, which share their entire genetic constitution with
the mother plant (Iyer and Degani 1997). In polyembryonic cul-
tivars the zygotic embryo may produce morphological and ge-
netic diversity (Gálvez-López et al. 2010). However, systematic
breeding is difficult because it is not always possible to obtain
zygotic embryos (Ochoa et al. 2012), and thus, polyembryonic
seeding selection has been carried out to exploit the diversity
in polyembryonic populations generated by natural mutation
(Knight and Schnell 1993). On the other hand, in the US, because
of the large number of monoembryonic cultivars, general breed-
ing has been carried out, and many varieties with fewer peculiar-
ities have been produced (Bally, Lu and Johnson 2009). In com-
parison with commercially important cultivars, polyembryonic
mangoes exhibit a stronger turpentine-like aroma and a stringy
flesh characterized by many distinct tough fibers (Purseglove
and Anacardiaceae 1974). Consumers in temperate countries
find such flavor and texture characteristics unpleasant (Ollé et al.
1998). Therefore, most fresh mangoes and mango derived prod-
ucts sold on the world market originate from monoembryonic
cultivars. Aiko mainly contains $\delta$-3-carene and showed a com-
position more similar to that of Irwin, a pollen parent, than the
seed parent Chiin Hwang No. 1. However, among the volatile
components of Aiko, the proportion of sesquiterpenes was more
than that in Irwin and Chiin Hwang No. 1 (Figure 3). Monoter-
penes are biosynthesized via the methylerythritol phosphate
(MEP) pathway in plastids, whereas sesquiterpenes are produced
Volatile profiling of 17 mango cultivar fruits

Recent advances in molecular genetics have allowed the identification of pollen parents, which is difficult to be identified using conventional SSR markers (Ravishankar et al. 2011). It has been reported that mangoes are genetically classified into 3 clusters according to USA (Florida), India, and Asia (Yamanaka et al. 2019). Our results suggest that the genetic cluster is closely related to the aroma component in the fruit. Irwin, a grandchild of Haden, and most of the cultivars derived from Haden were included in the same cluster in the classification of aroma components. The volatile components of Haden have been reported to be mainly composed of 3-carene (Pino et al. 2005), and its closely related cultivars inherited the similar aroma components. Haden derived cultivars have been widely distributed in North America and East Asia, such as in Taiwan and Japan, suggesting that odor properties of 3-carene match the consumers’ preferences in these areas. In contrast, cultivars originated in Thailand and India contained relatively low levels of 3-carene. These results imply that the cultural preference in Central and Southeast Asia is different from that in other areas.

Our results suggested that mono- and sesquiterpenes are major components of mango fruit volatiles. In addition to the terpenes, acetoin and lactones with 4 to 10 carbons were reported to be contained in the mango flavor (Chauhan, Raju and Bawa 2010). However, the report which suggested the acetoin in mango flavor used canned mango puree (Hunter et al. 1974). In addition, acetoin was reported to be formed by fermentation of mango juice with Penicillium expansum (Duartea, Delgadillo and Gil 2006). Pino et al. reported that acetoin was not detected in all of 20 mango cultivars tested. Considering them, acetoin may not be involved in the fresh mango flavor. In contrast to acetoin, lactones have been reported to contribute to fruit aroma as well as monoterpenes (Hadi et al. 2013). The previous study suggested that the SPME method showed low sensitivity than the solvent extraction method (Mahattanatawee, Goodner and Baldwin 2005). In addition, terpenes were reported to be major and important constituents in mango flavor, while levels of lactones and other esters were extremely low (Pino et al. 2005). Our results may be due to the low concentrations of these compounds. However, the major mono- and sesquiterpenes were significantly detected, and the difference in cultivars were clearly characterized.

In mango, the proportion of monoterpenes decreases as the fruit matures, and the proportion of alcohols and esters increases in Alphonso (Pandit et al. 2009) and Irwin (Shivashankara et al. 2006). It has also been reported that the aroma changes depending on the processing method and texture (Bonneau et al. 2018). In the future, by investigating the difference of aroma components among cultivars depending on the harvest time and maturity stage, should provide an index to determine the storage characteristics and the harvest time suitable for the cultivars. Breeding of mango takes 3-10 years to confirm the fruit traits (Bally, Lu and Johnson 2009), and it is required to improve the efficiency of the individual selection method at an early stage. Therefore, it is important to collect data on the correlation between fruits and aroma components of various parts such as leaves, bark, and flowers, along with genetic information. Our results provide important information for evaluation of the mango fruit quality and establishment of efficient mango breeding systems.

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Data availability

The data underlying this article are available in the article and in its online supplementary material.
Author contribution

T.M. and S.K. designed the study and performed statistical analysis. K.S. and R.K. performed chemical analyses and statistical analyses. K.I., S.K., and S.S. prepared and treated the plant materials. All authors have reviewed and approved the final version of the manuscript.

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Disclosure statement

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