Bioscience, Biotechnology, and Biochemistry, 2021, Vol. 85, No. 8, 1789-1797

https://doi.org/10.1093/bbb/zbab097
Advance access publication date: 31 May 2021
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Volatile profiling of fruits of 17 mango cultivars by HS-SPME-GC/MS combined with principal component analysis

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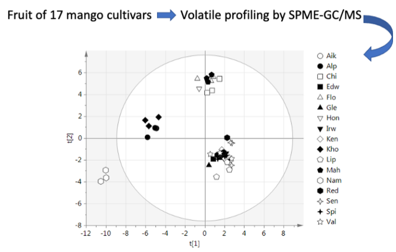
ABSTRACT

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 primary component analysis.

Keywords: Aiko, gas chromatography-mass spectrometry (GC-MS), mango cultivars, *Mangifera indica,* solid-phase microextraction (SPME)

Received: 18 March 2021; **Accepted:** 18 May 2021

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 (Sasaki *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 (Aprea *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 green house 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, China 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,

Table 1. Material seventeen mango cultivars

Cultivar number	Cultivar name	Origin	Embryo mono or poly	Candidate parent (seed)[a]	Candidate parent (pollen)[a]	Group in Figure 2
1	Aiko	Japan	M	Chiin Hwang No. 1	Irwin	1
2	Alphonso	India	M	unknown	Unknown	3
3	Chiin Hwang No. 1	Taiwang	M	White	Kent	2
4	Edward	USA	M	Haden	Unknown	1
5	Florigon	USA	P	Haden	Unknown	2
6	Glenn	USA	M	Haden	Unknown	1
7	Irwin	USA	M	Lippens	Haden	1
8	Kent	USA	M	Brooks	Haden	1
9	Khom	Thailand	P	Unknown	Unknown	3
10	Lippens	USA	M	Haden	Unknown	1
11	Maha Chanook	Thailand	P	Unknown	Unknown	2
12	Nam Doc Mai	Thailand	P	Unknown	Unknown	4
13	Hong Long	Taiwang	M	Irwin	Unknown	2
14	Red Keitt	Taiwang	M	Keitt	Yu-Win No.6	1
15	Sensation	USA	M	Brooks	Haden	1
16	Spirit of 76	USA	M	Zill	Haden	1
17	Valencia Pride	USA	M	Haden	Unknown	1

[a]Parentage was described in literatures of Yamanaka *et al.* (2019).

Table 2. Volatile compounds in fruits of seventeen mango cultivars

Peak ID	Category	Compound name	Retention indices (RI)	RI in literature	Similarity indices
1	Acid	Butyric acid	802	CC[a]	
2		Acid-like	816		
3		Lactone-like	847		
4	Monoterpene	α-Pinene	928	CC	
5		Monoterpene-like 1	931		
6	Monoterpene	Camphene	938	CC	
7		Unidentified (aliphatic compound)	954		
8	Monoterpene	β-Pinene	959	943[b]	90
9	Monoterpene	β-Phallandrene	967	969[b]	90
10		Monoterpene-like 2	1002		
11	Aldehyde	Octanal	1004	CC	
12	Monoterpene	α-Phallandrene	1006	CC	
13	Monoterpene	δ-3-Carene	1011	CC	
14	Monoterpene	α-Terpinene	1015	CC	
15	Monoterpene	(*E*)-Caren-2-ol	1022	1136[b]	92
16	Monoterpene	α-Limonene	1026	CC	
17	Monoterpene	(*Z*)-β-Ocimene	1031	CC, 1040[c], 1039[d]	98
18		Unidentified (acid-like)	1036		
19	Monoterpene	(*E*)-β-Ocimene	1040	CC, 1050[c], 1050[d]	93
20		Monoterpene-like 3	1046		
21	Monoterpene	γ-Terpinene	1048	CC	
22	Monoterpene	α-Terpinolene	1070	CC	
23	Monoterpene	*p*-Cymenene	1072	CC	
24		Unidentified (aromatic compound)	1074		
25	Aldehyde	Nonanal (internal standard)	1106	CC	
26	Monoterpene	2,6-Dimethyl-1,3,5,7-octatetraene	1116	1134[e]	93
27		Monoterpene-like 4	1123		
28	Aliphatic compound	2,4,6-Octatriene	1127	1143[f]	93
29		Unidentified	1130		
30		Unidentified	1137		
31		Unidentified	1139		
32	Monoterpene	Terpinen-4-ol	1170	CC, 1177[c]	93
33	Monoterpene	*p*-Cymen-8-ol	1179	1183[c]	90
34	Aromatic ester	Methyl salicylate	1205	1190[c], 1192[e]	94
35	Aromatic acid	Ethyl phenylacetate	1245	1244[c]	92
36		Monoterpene-like 5	1256		
37		Unidentified (acid-like)	1260		
38		Unidentified (acid-like)	1284		
39	Sesquiterpene	α-Ylangene	1358	1367[f], 1368[g,h]	90
40		Unidentified (ester-like)	1377		
41		Unidentified (ester-like)	1380		
42	Sesquiterpene	α-Copaene	1385	1376[c,d]	92
43	Sesquiterpene	α-Gurjunene	1429	1407[c], 1408[i]	90
44	Sesquiterpene	β-Caryophyllene	1440	CC, 1418[c], 1420[d]	96
45	Sesquiterpene	β-Ylangene	1446	1421[f]	90
46	Sesquiterpene	α-Guaiene	1453	1439[c], 1437[i], 1440[j]	91
47		Sesquiterpene-like 1	1465		
48	Sesquiterpene	Humulene	1473	CC,1454[c], 1442[f]	96
49	Sesquiterpene	β-Copaene	1479	1436[k]	
50	Sesquiterpene	Alloaromadendrene	1487	1461[d], 1460[i], 1448[j]	92
51	Sesquiterpene	4,5-di-epi-Aristolochene	1486	1465[c]	91
52	Sesquiterpene	Germacrene-D	1503	1480[c,i]	90
53	Sesquiterpene	γ-Gurjunene	1504	1472[c,i]	91
54	Sesquiterpene	Selinene	1512	1484[c]	90
55	Sesquiterpene	Valencene	1516	1491[c], 1492[i]	90
56		Sesquiterpene-like 2	1519		
57	Sesquiterpene	δ-Guaiene	1527	1500[f]	91
58	Sesquiterpene	γ-Muurolene	1534	1498[f]	90

Table 2. Continued.

Peak ID	Category	Compound name	Retention indices (RI)	RI in literature	Similarity indices
59	Sesquiterpene	δ-Cadinene	1542	1523[c], 1521[d]	91

[a]Identified by cochromatography (CC) with authentic standards.
[b]NIST Retention Index Library ver. 11.
[c]Pino *et al.* (2005).
[d]Asai, Matsukawa and Kajiyama (2016).
[e]Flamini, Cioni and Morelli (2002).
[f]Babushok, Linstrom and Zenkevich (2011).
[g]Siani *et al.* (2004).
[h]Kovats index agreed with Sibanda *et al.* (2004).
[i]Kovats index agreed with Babushok *et al.* (2011).
[j]Oyedeji, Ekundayo and König (2003).
[k]Andriamaharavo (2014).

Edward, Florigon, Glenn, Hong Long, Irwin, Kent, Khom, Lippens, Maha Chanook, Nam Doc Mai, Red Keiit, Sensation, Spirit of 76, and Valencia Pride; Table 1) were collected at the Experimental Farm of Kindai University (34° 2′N, 135° 11′E, 17 m ASL), located in Wakayama Prefecture, Japan. The trees of these cultivars were grown using commercial methods in a plastic greenhouse under controlled conditions (winter: minimum 2 °C [room] and 10 °C [soil]; summer: maximum 35 °C [room] and 31 °C [soil]). Each sample was collected 3 mature fruits from 1 tree (average height: 2.5 m; age: 12-15 years, life span: 40-50 years) that were propagated by grafting. All varieties were grafted onto the uniform polyembryonic rootstock of the Taiwanese wild-type. The fruits of "Irwin" were collected in August 2019 whereas those of the other 16 cultivars were collected from late August to September 2019. The experimental farm personnel identified and collected the mature fruits. The harvested fruits were stored at −20 °C before use.

HP-SPME-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 portion (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 cultivars and checked that nonanal was not detected in all samples, 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, Kyoto, Japan). Headspace volatile organic compounds (VOCs) were extracted using an SPME fiber coated with 50/30 µm of divinylbenzene/carboxen/polydimethylsiloxane at 50 °C for 60 s with continuous agitation at 600 s^{-1}. The SPME fiber was inserted into the injection port for 60 s at 230 °C to desorb the VOCs. An Rtx-5MS capillary column (30 m × 0.25 mm [0.25 µm], Restek, Bellefonte, PA, USA) was used, and helium was used as a carrier gas at a linear velocity of 38.1 cm/s. The oven temperature was set at 50 °C for 5 min; it was then increased to 330 °C at a rate of 15 °C min^{-1} and maintained for 6 min. The mass spectra were obtained in electron ionization mode at 70 eV with a scanning range of *m/z* 85-500 and a scanning speed of 10 000 scan s^{-1}. The MS ion source and interface temperatures were 200 °C and 250 °C, respectively.

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 compounds. Compounds were annotated under the condition of processing a similarity index of more than 90, and major components 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.

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 annotated, 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, Sensation, Spirit of 76, and Valencia Pride were *δ*-3-carene, whereas Chiin Hwang No. 1, Florigon, Maha Chanook, and Hong Long contained large amounts of *α*-terpinolene. (*Z*)-*β*-Ocimene accounted for 71% of the main components of Alphonso, whereas Khom had 60% of its isomer, (*E*)-*β*-ocimene. Nam Doc Mai had a higher proportion of *α*-limonene than the other cultivars.

Principal components analysis

To compare the volatile components among cultivars, the peak patterns (including unidentified peaks) of HS-SPME-GC/MS were

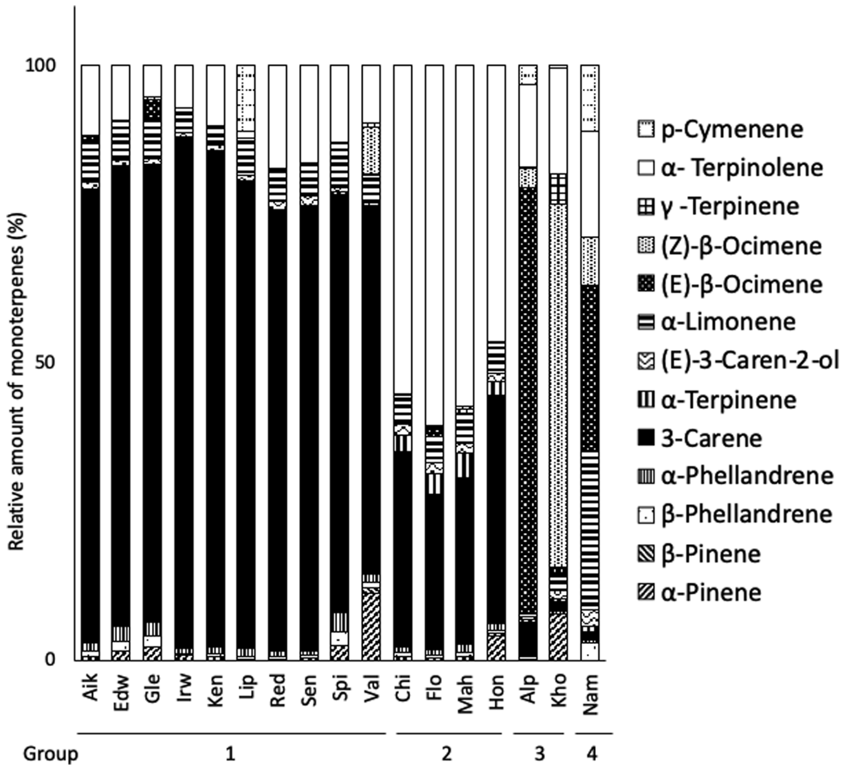


Figure 1. Comparison of the monoterpene composition of fruit in 17 mango cultivars. Cultivar names are represented by 3 letters: Aiko (Aik), Alphonso (Alp), Chiin Hwang No. 1 (Chi), Edward (Edw), Florigon (Flo), Glenn (Gle), Hong Long (Hon), Irwin (Irw), Kent (Ken), Khom (Kho), Lippens (Lip), Maha Chanook (Mah), Nam Doc Mai (Nam), Red Keiit (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 Keitt, 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 Chiin Hwang No. 1, Maha Chanook, Florigon, 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 PC1. 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-caren as the main compound (Figure 2). The second largest cluster was Group 2, and the cultivars in this cluster contain more α-terpinolene than other cultivars. The Alphonso and Khom clusters contain a lot of β-ocimene, but 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-caren, 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 Florigon, whereas (E)-β-ocimene was the main component in the Indian variety Alphonso. Florigon and 2 Taiwanese cultivars, Chiin 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 terpineneiol. 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, ie polyembryonic types and monoembryonic types (Mukherjee 1953). Polyembryonic cultivars such as Nam Doc Mai are common in Asia, and they have been cultivated traditionally

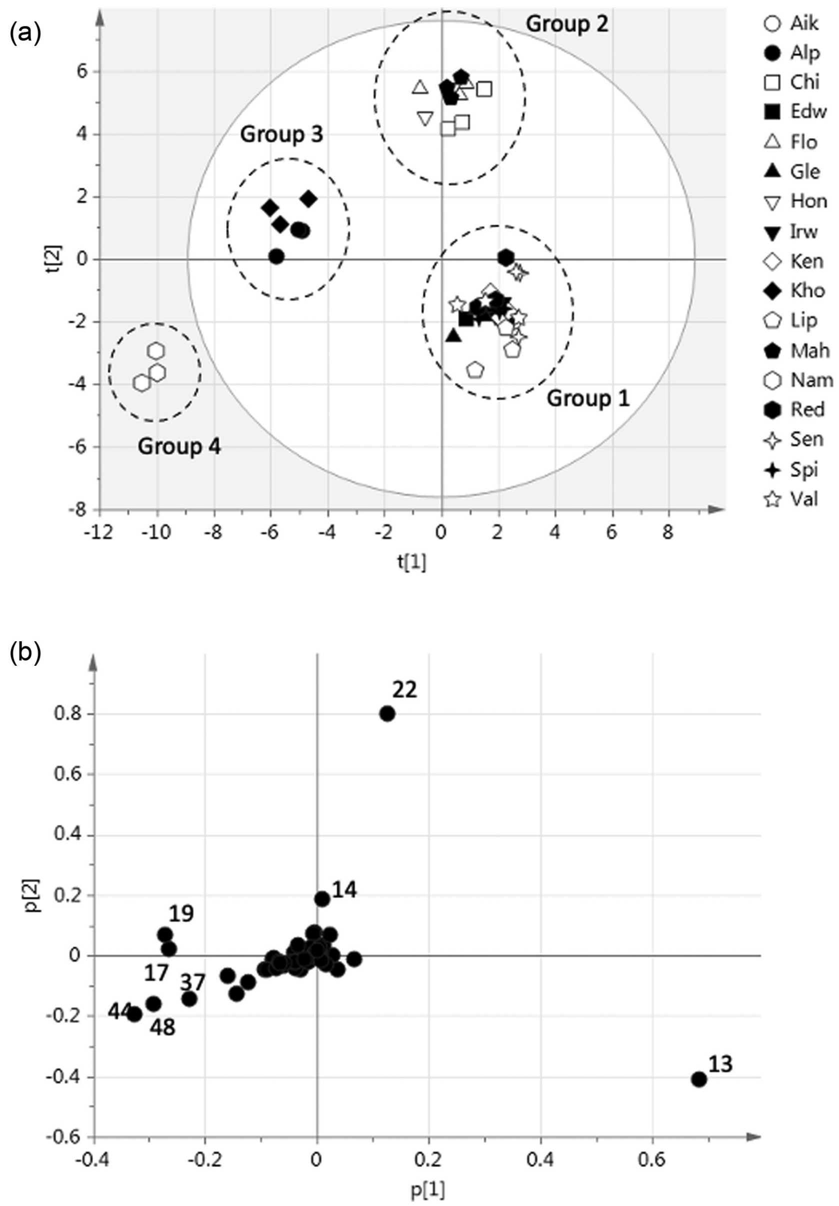


Figure 2. Principal component analysis (PCA) model of 17 mango cultivars based on HS-SPME-GC/MS analysis. (a) Score plot for principal component 1 (PC1) and PC2 ($R^2X[1] = 0.280$, $R^2X[2] = 0.203$), showing different symbols for the different cultivars: Aiko (open circles), Alphonso (closed circles), 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.

(Purseglove and Anacardiaceae 1974) . In polyembryonic mango, each seed contains 1 sexual embryo and several somatic or nucellar ones, which share their entire genetic constitution with the mother plant (Iyer and Degani 1997). In polyembryonic cultivars the zygotic embryo may produce morphological and genetic 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 seedling selection have 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 breeding has been carried out, and many varieties with fewer peculiarities have been produced (Bally, Lu and Johnson 2009) . In comparison 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 products sold on the world market originate from monoembryonic cultivars. Aiko mainly contains δ-3-carene and showed a composition 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). Monoterpenes are biosynthesized via the methylerythritol phosphate (MEP) pathway in plastids, whereas sesquiterpenes are produced

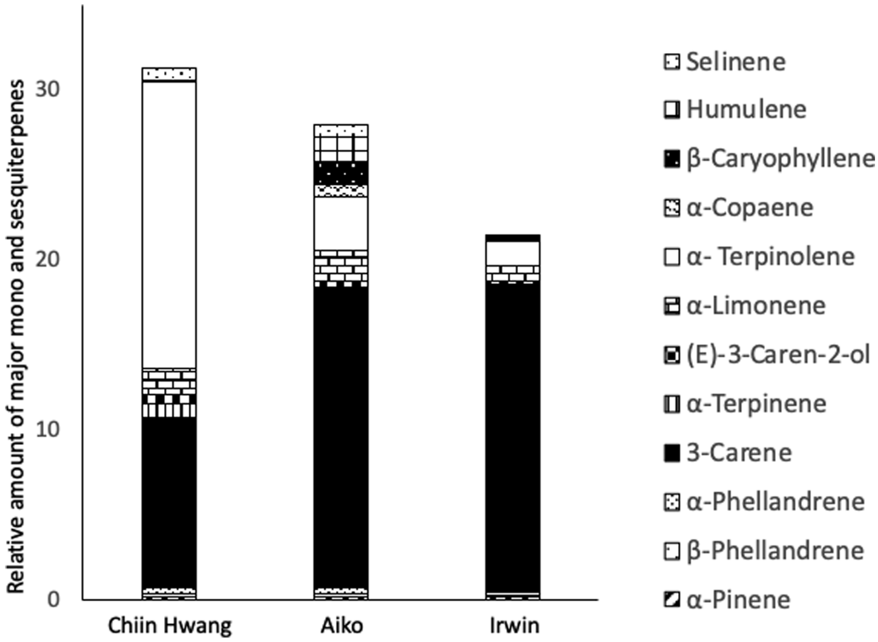


Figure 3. Comparison of mono- and sesquiterpene composition of Aiko and its parents, Chiin Hwang No. 1 and Irwin. Different bar patterns correspond to different monoterpenes as shown in the right panel.

via the mevalonate pathway in the cytosol. Our results suggest that the regulation of these 2 terpenoid pathways are independently inherited from the parents.

Recently, 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 δ-3-carene match the consumers' preferences in these areas. In contrast, cultivars originated in Thailand and India contained relatively low levels of δ-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.

Acknowledgments

We are grateful to the technical staff of Yuasa Experimental Farm, Kindai University, for the collection of mango fruits. We are also deeply grateful to Dr. Akihiko Sato for his invaluable guidance and advice.

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.

Funding

None declared.

Disclosure statement

No potential conflict of interest was reported by the authors.

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