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# Morphological and Chemical Analysis of 16 Avocado Accessions (*Persea americana*) From China by Principal Component Analysis and Cluster Analysis

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**Abstract**

The physicochemical composition of avocado fruit has been well reported, but there is little detail on Chinese native avocado varieties. The present study investigated the morphological characteristics, oil contents, and fatty acid compositions of 16 avocado accessions grown in the tropical and subtropical regions of China. Eight fatty acids were identified and quantified by GC-MS. The major fatty acids of avocado pulp were palmitic, oleic, and linoleic acids, accounting for 78-91% of the total fatty acids content. The analysis of one-way variance (ANOVA) of the data revealed morphological and chemical differences between most of avocado accessions. Moreover, 16 avocado accessions were distinguished through a PCA scores scatter plot and cluster analysis based on fatty acid profiles. The results identified some remarkable characteristics of avocado accessions from different places of collection.

**Keywords:** avocado, pulp, fatty acids, principal component analysis, cluster analysis

## 1. Introduction

Avocado (*Persea americana* Mill.), a member of the family Lauraceae of the order Laurales, is a plant native to Central America, South America, and Mexico (Schaffer et al., 2012). The avocado is among the most economically important subtropical/tropical fruit crops in the world, and production and consumption levels have increased dramatically during the last 150 years (Schaffer et al., 2012). One factor contributing to this marked increase was the constant expansion of avocado products into new markets in parts of the world where avocado was previously unknown or scarcely available (Schaffer et al., 2012). Avocados were first introduced to the Taiwan province of China in 1918 (Papademetriou, 2000), thus allowing the rapid propagation of superior varieties to develop an industry producing avocados with superior plant characteristics and fruit quality. Since the late 1950s, hundreds of avocado varieties have been introduced in China successively from the United States, Mexico, and Central America (Ge et al., 2017a). Breeding and selection programs were undertaken and are ongoing to this day mainly by CATAS, GSSASRI, Guangxi Vocational and Technical College, and other state-owned or private farms, leading to the selection of more than a dozen high-quality avocado varieties (Ge et al., 2017a). Meanwhile, natural hybridization between avocado varieties often occurs, producing many new avocado hybrids in state-owned or private farms. Several local avocado selections have also gradually developed in relatively isolated growing zones because of local unique geographical environments. Nowadays, some Chinese native superior avocado varieties are widely cultivated in the tropical and subtropical regions of China (Ge et al., 2017a).

Particular chemical composition of avocado are associated with nutritive and health effects (Dreher & Davenport, 2013; Galvão et al., 2014; Ge et al., 2017b). In terms of oil content, avocado fruit is exceeded only by the fruits of the palm and olive trees (Knothe, 2013). Remarkably, the lipid content in avocado can reach 5% to 30% of the fruit fresh weight, depending on the seasonality and planting conditions (Ge et al., 2017a). Avocado fruit lipids contains 50% to 60% monounsaturated fatty acids and 10% to 15% polyunsaturated linoleic and linolenic acids

(Giraldoa & Moreno-Piraján, 2012; Pedreschi et al., 2016). Furthermore, avocado fruit lipids could be used in non-food industries, for example, as an alternative biodiesel source instead of the conventional petroleum-based diesel fuel (Giraldoa & Moreno-Piraján, 2012; Knothe, 2013). In addition, the high non-saturated content of avocado fruit lipids provided superior skin permeability and sunscreen performance, and could be used in sunscreen cream as emulsifier (Santo et al., 2014).

Globally, the Hass and Fuerte avocado cultivars are the most commercially valuable, accounting for about two-thirds of avocado production (Schaffer et al., 2012). Therefore, these two cultivars have been the subject of most studies on the properties influencing avocado quality (Hurtado-Fernandez et al., 2011, 2014, 2015; Rodríguez-Carpena et al., 2011). However, no similar studies have yet been published on Chinese native avocado accessions. Thus, the objective of the present study was to determine morphological characteristics, oil contents, and fatty acid compositions of avocado fruit from 16 avocado accessions collected from the tropical and subtropical regions of China. The 16 avocados were distinguished using chromatography of its oil combined with principal component analysis and cluster analysis. The resulting information will be used to evaluate the potential avocado germplasms with high-quality properties for use as food or for industrial biodiesel production.

## 2. Materials and Methods

### *2.1 Plant Material, Reagents, and Sample Preparation*

The 16 avocado accessions (*P. americana* var. *guatemalensis*) used in the present study were obtained as follows: six native avocado accessions (RN-1, RN-5, RN-11, RN-12, RN-15, and RN-16) and one foreign cultivar (Hass) were obtained from the Chinese Academy of Tropical Agricultural Sciences (Danzhou city, Hainan province, China: location 19.52°N, 109.57°E); three native accessions (RN-21, RN-22, and RN-23) were obtained from the Daling State Farm (Baisha city, Hainan province, China: 19.23°N, 109.23°E); five native accession (RN-24, RN-25, RN-26, RN-27, and RN-28) were obtained from the Mengmao State Farm (Ruili city, Yunnan province, China: 24°N, 97.83°E); one native accession (RN-29) was obtained from the Baofeng State Farm (Ledong city, Hainan province, China: 19.23°N, 109.23°E). 18 mature fruits of each accession were randomly collected and immediately transported to the laboratory in standard foam boxes used for export packaging. The fruit samples were maintained at 5 °C to 6 °C. The pulps were separated from the fruits, homogenized using a domestic blender, and then stored at 4 °C for a maximum of one week before analysis.

### *2.2 Morphological Characteristics and Chemical Assays*

The length, breadth, and weight of each fruit were measured. Nine replicates (fruits and seeds) were randomly selected to measure per accession.

Oil content was evaluated using the description of Ge et al. (2017b). Nine mature fruits were randomly collected from 18 fruits of each accession, and the pulps of theirs were mixed respectively. The avocado pulps were dried and ground to a powder, and the dry powders (5 g) were transferred to a cylindrical filter paper, to which absolute ether (50 °C) was added at a material-to-solution ratio of 1:20. The mixture solutions were stood over night. The pulp oils were sequentially extracted using a Soxhlet extractor for 6 h. Finally, the extracted solutions were evaporated using a rotary evaporator, and the residue was weighed. The total lipid content was expressed as g/100 g on a fresh weight (FW) basis. The experiments were performed in triplicate for each accession.

The fatty acid profiles were determined as described by Ge et al. (2017b). Nine mature fruits were randomly collected from 18 fruits of each accession, and the pulps of theirs were mixed respectively. The oils extracted from avocado pulps (40 μL) were saponified at 80 °C for 30 min after adding 5 mL NaOH-MeOH (0.2 mol/L). After cooling, 2.5 mL $BF_3$-MeOH (14%) was added to the mixtures to allow methyl esterification at 80 °C for 30 min. After the addition of 2 mL saturated NaCl and 4 mL *n*-hexane, the solutions were heated under reflux for 15 min. The upper layers were collected, filtered through a 0.22-μm filter membrane, and then analyzed for fatty acids by GC-MS.

GC-MS conditions were evaluated using the method of Ge et al. (2017b). The sample volume injected in the gas-chromatograph was 1 μL. The mass spectrometer was operated in the electron impact mode at 70 eV in the scan range of 35 to 400 m/z. The fatty acid methyl esters (FAMEs) were identified by comparing the retention times of the peaks with those of commercial standards, and by computer matching of their corresponding mass spectra with those reported in the NIST 2011 library. The FAMEs were quantified against methyl nonadecanoate, which was added as an internal standard and then quantified using the calibration curves of the respective FAMEs ($R^2 \geq 0.995$). The contents of the FAMEs were expressed as mg/100 g FW. The experiments were carried out using three replicates.

### *2.3 Statistical Analyses*

Significant differences and principal components analysis (PCA) were analyzed using SPSS version 20.0 (SPSS Inc., Chicago, IL, USA). Significant differences among the fruit characteristics, oil contents, and fatty acid compositions of the 16 avocado accessions were verified by one-way analysis of variance, and Duncan's multiple comparison test was used to determine the statistical significance of differences between means at a 95% confidence level. The results were presented as the mean±standard deviation of three measurements. The distance matrix was subjected to cluster analysis by the unweighted pair-group method (UPGMA, Sneath & Sokal, 1973), a SAHN clustering technique (Sneath & Sokal, 1973), which compresses the patterns of variation into two-dimension branch diagrams (dendrograms). The dendrogram was constructed using a Jaccard's formula with NTSYS pc 2.1 statistical package (Rohlf, 2000).

## 3. Results and Discussion

### *3.1 Morphological Characteristics Analyses*

Fruit weight is one of the most important indices in avocado production (Schaffer et al., 2012). As shown in Table 1, large differences in fruit weight were observed between most of the avocado accessions ($p < 0.05$). The fruit of RN-15 was the heaviest (0.51±0.04 kg), whereas the fruit of RN-12 was the lightest (0.09±0.01 kg). With the exception of RN-12, the weights of the fruits of the 14 native Chinese avocado accessions all exceeded that of the Hass cultivar. The fruit lengths of the 16 avocado accessions ranged from 5.47±0.71 cm (RN-12) to 19.95±1.87 cm (RN-21), with significant differences between most of the accessions ($p < 0.05$; Table 1). The fruit breadths of the 16 avocado accessions were also presented in Table 1, showing small differences between most accessions ($p < 0.05$). The highest fruit breadth was found in RN-15 (8.92±0.38 cm), while the lowest was found in RN-12 (5.42±0.31 cm). Schaffer et al. (2012) suggested that the fruit shapes of the avocado cultivars was exceedingly rich around the world, such as Bacon and Hass for ovate, Ettinger for pyriform, and Fuerte for pyriform with a distinct neck, etc. Based on the fruit lengths, breadths, and appearances (Table 1 and Figure 1), the fruit shapes of the avocado accessions were mainly pyriform (RN-1, RN-11, RN-21, RN-23, and RN-27) and ovate (RN-5, RN-15, Hass, RN-22, RN-24, RN-26, RN-28, and RN-29). The exceptions were RN-12, which was round, and RN-16 and RN-25, which were pyriform with long, narrow necks.

Table 1. Fruit characteristics (mean value±standard deviation, $n = 9$) of 16 avocado accessions grown in southern China

| Accession | Fruit characteristic | | |
|---|---|---|---|
| | Fruit weight (kg) | Fruit length (cm) | Fruit breadth (cm) |
| RN-1 | 0.47±0.02a | 16.76±0.73a | 7.76±0.60a |
| RN-5 | 0.41±0.02d | 10.49±0.77b | 8.63±0.62bc |
| RN-11 | 0.32±0.02f | 15.03±1.35cd | 7.08±0.63d |
| RN-12 | 0.09±0.01g | 5.47±0.71f | 5.42±0.31e |
| RN-15 | 0.51±0.04c | 12.30±0.50g | 8.92±0.38c |
| RN-16 | 0.34±0.03f | 16.88±1.30a | 6.91±0.31d |
| Hass | 0.18±0.03h | 8.30±0.46h | 6.19±0.42f |
| RN-21 | 0.48±0.04ab | 19.95±1.87i | 7.02±0.31d |
| RN-22 | 0.33±0.03f | 9.61±0.67j | 8.21±0.37b |
| RN-23 | 0.30±0.01i | 14.75±0.96cde | 6.79±0.47d |
| RN-24 | 0.38±0.03e | 10.54±0.66b | 8.52±0.39bc |
| RN-25 | 0.44±0.03j | 14.20±0.65ce | 7.63±0.26a |
| RN-26 | 0.39±0.03de | 12.23±0.60g | 7.91±0.21ab |
| RN-27 | 0.41±0.02d | 15.53±1.28d | 7.78±0.46a |
| RN-28 | 0.26±0.02k | 8.32±0.58h | 7.49±0.52a |
| RN-29 | 0.50±0.02bc | 13.89±0.78e | 8.59±0.16bc |

*Note*. Different letters within the same column are significantly different ($p < 0.05$).

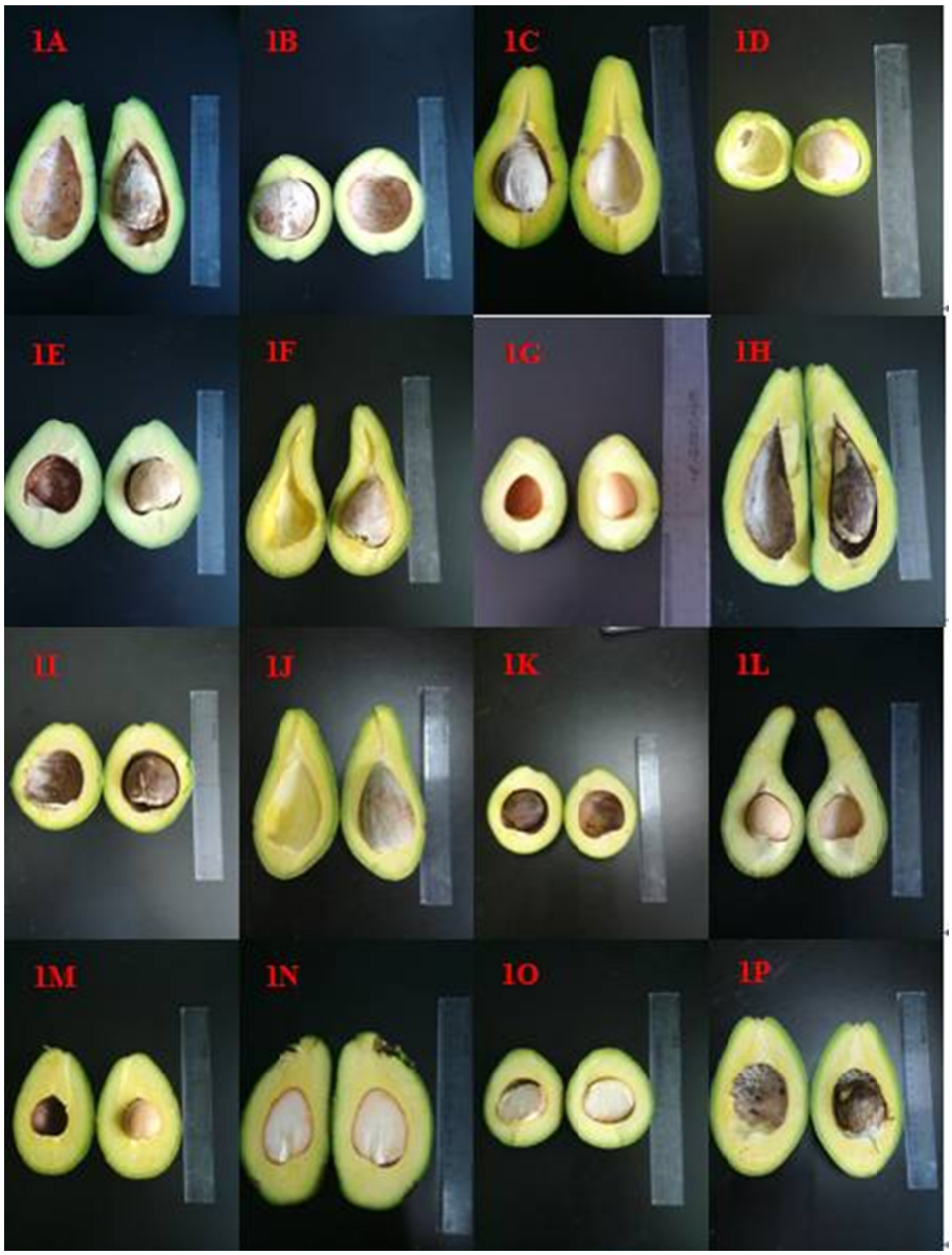


Figure 1. Photographs of the fruits and seeds of the 16 avocado accessions grown in southern China. RN-1 (1A); RN-5 (1B); RN-11 (1C); RN-12 (1D); RN-15 (1E); RN-16 (1F); Hass (1G); RN-21 (1H); RN-22 (1I); RN-23 (1J); RN-24 (1K); RN-25 (1L); RN-26 (1M); RN-27 (1N); RN-28 (1O); RN-29 (1P)

### *3.2 Fatty Acid Profiles Analyses*

The main feature of avocado was its high lipid content (Schaffer et al., 2012). The total lipid levels of the pulps of the 16 avocado accessions ranged from 1.73±0.06 to 8.75±0.07 g/100 g FW (Figure 2). RN-5 and Hass exhibited high lipid levels of 8.75±0.07 and 8.57±0.02 g/100 g FW, respectively, while RN-22, RN-15, and RN-12 had intermediate levels of 7.34±0.03, 7.08±0.03, and 6.98±0.01 g/100 g FW, respectively. The remaining 11 avocado accessions exhibited lower lipid levels ranging from 1.73±0.06 to 6.53±0.05 g/100 g FW. Significant differences in lipid levels were found among the avocado accessions ($p < 0.05$) (Figure 2). Galvão et al. (2014) determined the total lipid levels of the pulps of three avocado cultivars from Brazil through the same Soxhlet extraction as our experiment, and found that the lipid levels ranged from 11.90±0.62 to 16.20±0.13 g/100 g FW, which were a considerably higher than the total lipid levels of the pulps of the 16 avocado accessions in this study. Other studies have reported that total lipid levels of the pulps varied from 6.73 to 43.5 g/100 g FW through the Soxhlet extraction for the avocado cultivars from Portugal, Mexico, and Venezuela (Gómez-López,

1999, 2002; Villa-Rodríguez et al., 2011; Vinha et al., 2013); these previously reported values were mostly higher than those found in the present study. We inferred that the different cultivation conditions of the avocado accessions could have the main effect on the variation of the total lipid levels of the pulps.

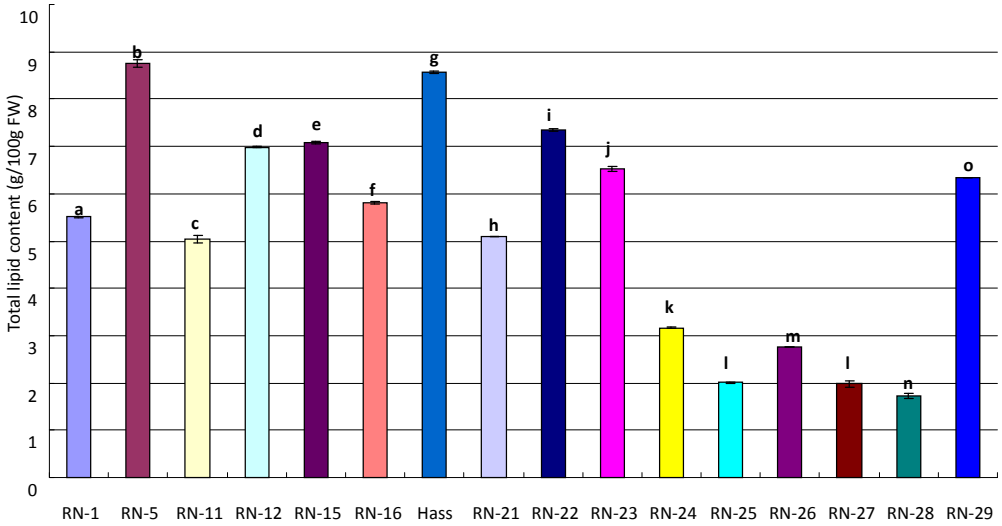


Figure 2. Total lipid contents (mean value±standard deviation g/100 g FW, $n = 3$) of 16 avocado accessions grown in southern China. Vertical bars represent standard deviations. Different letters indicate significant differences at $p < 0.05$

The fatty acid compositions of the pulps of the 16 avocado accessions were presented in Table 2. The same eight fatty acids were found in the pulps of all 16 avocado accessions, although the compositions were significantly different among most of the accessions ($p < 0.05$). The major fatty acids (≥ 15%, the percentage of the individual fatty acid out of the total fatty acid content) in the avocado pulp oil quantified in the present study were palmitic acid (C16:0), linoleic acid (C18:2), and oleic acid (C18:1), and intermediate amounts (1% to 15%, the percentage of the individual fatty acid out of the total fatty acid content) of palmitoleic acid (16:1), linolenic acid (C18:3), and stearic acid (C18:0) were detected. Small amounts (≤ 1%, the percentage of the individual fatty acid out of the total fatty acid content) of arachic acid (C20:0) and myristic acid (C14:0) were found. These findings agreed with previous studies reporting that palmitic, oleic, and linoleic acids were the dominant fatty acids in avocado pulp oil (Ozdemir & Topuz, 2004; Pedreschi et al., 2016; Rohman et al., 2016). Previous studies indicated that the content of oleic acid had a considerably higher than those of other fatty acids (Dreher & Davenport, 2013; Galvão et al., 2014; Ferreyra et al., 2016), while the content of oleic acid had almost the same as that of linoleic acid and slightly lower than that of palmitic acid in this study. In the present study, more than 67% of the total fatty acids (TFA) in the avocado pulp oil were unsaturated, with the remaining 33% being saturated (Table 3). The total content of unsaturated fatty acids (ΣUFA) ranged from 1090.75±23.78 mg/100 g FW in RN-28 to 5689.39±140.63 mg/100 g FW in RN-5. The total content of saturated fatty acids (ΣSFA) varied between 492.26±24.16 mg/100 g FW in RN-28 and 2930.02±56.58 mg/100 g FW in RN-5, while TFA varied from 1583.01±47.94 mg/100 g FW in RN-28 to 8619.41±197.21 mg/100 g FW in RN-5. Palmitic acid was the most abundant SFA, with noticeable differences in palmitic acid content observed between avocado samples ($p < 0.05$); RN-5 had the greatest content of palmitic acid (2813.95±54.15 mg/100 g FW), while RN-28 had the lowest content (435.65±23.47 mg/100 g FW). The UFAs linoleic and oleic acids were the second most abundant fatty acids and were found in similar amounts. The ΣUFA/ΣSFA ratios in the 16 avocado accessions ranged from 1.49 to 2.41, which were in accordance with those of the Collinson and Barker cultivars but below that of the Fortuna cultivar (3.49) (Galvão et al., 2014).

Table 2. Fatty acid compositions (mean value±standard deviation, mg/100 g FW, $n$ = 3) in the pulps of 16 avocado accessions grown in southern China

| Fatty Acids | Accessions | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RN-1 | RN-5 | RN-11 | RN-12 | RN-15 | RN-16 | Hass | RN-21 | RN-22 | RN-23 | RN-24 | RN-25 | RN-26 | RN-27 | RN-28 | RN-29 |
| *Saturated Fatty Acids (SFAs)* | | | | | | | | | | | | | | | | |
| Myristic acid (C14:0) | 14.92 ± 0.96ad | 15.43 ± 0.57ab | 11.73 ± 0.61e | 21.62 ± 0.76g | 15.46 ± 0.44ab | 12.90 ± 0.16h | 17.75 ± 0.28i | 16.63 ± 1.23c | 16.31 ± 0.73bc | 15.87 ± 0.5abc | 10.58 ± 0.46f | 11.43 ± 0.27ef | 10.84 ± 0.18ef | 8.44 ± 0.09j | 10.59 ± 0.12f | 14.07 ± 0.32d |
| Palmitic acid (C16:0) | 1552.3 ± 54.92a | 2813.95 ± 54.15b | 1497.9 ± 38.83a | 2106.3 ± 63.77c | 2431.81 ± 33.69d | 1727.92 ± 6.73e | 2388.6 ± 68.14d | 1536.1 ± 84.38a | 2253.5 ± 59.20f | 1982.5 ± 96.15g | 1034.1 ± 32.08h | 507.14 ± 24.98ij | 716.48 ± 44.13k | 539.79 ± 16.47i | 435.65 ± 23.47j | 2125.9 ± 39.28c |
| Stearic acid (C18:0) | 69.89 ± 2.44ac | 74.15 ± 1.78b | 63.83 ± 1.25d | 94.47 ± 1.7e | 83.71 ± 4.23f | 73.20 ± 2.77ab | 67.94 ± 2.67c | 56.51 ± 3.51g | 90.33 ± 2.69h | 88.39 ± 3.57h | 34.89 ± 2.86i | 24.07 ± 0.74j | 29.28 ± 0.59k | 25.87 ± 0.91jk | 25.55 ± 0.50jk | 74.21 ± 1.51b |
| Arachic acid (C20:0) | 25.81 ± 0.67ab | 26.49 ± 0.08b | 21.01 ± 0.33c | 31.53 ± 0.70f | 25.38 ± 0.37a | 24.02 ± 0.24g | 32.86 ± 0.23h | 20.16 ± 0.42de | 28.33 ± 0.77i | 25.82 ± 0.47ab | 17.19 ± 0.11j | 20.55 ± 0.13cd | 19.62 ± 0.16e | 16.54 ± 0.29j | 20.47 ± 0.07cd | 22.52 ± 0.17k |
| *Unsaturated Fatty Acids (UFAs)* | | | | | | | | | | | | | | | | |
| Palmitoleic acid (16:1) | 298.24 ± 12.71ab | 1129.80 ± 47.27c | 620.70 ± 21.65d | 575.48 ± 38.78d | 526.63 ± 12.69e | 393.11 ± 6.36f | 1320.14 ± 81.95g | 478.35 ± 20.99h | 673.93 ± 10.18i | 469.87 ± 23.02h | 334.81 ± 9.77a | 272.52 ± 1.94b | 201.25 ± 12.56j | 177.57 ± 6.93jk | 140.36 ± 6.84k | 403.03 ± 12.08f |
| Oleic acid (C18:1) | 1779.3 ± 70.55a | 2225.91 ± 45.92b | 1387.2 ± 21.60c | 1668.3 ± 95.74d | 2090.11 ± 31.13e | 1999.57 ± 25.84f | 2544.3 ± 60.24g | 1043.4 ± 38.01h | 1917.5 ± 32.40i | 1546.7 ± 72.75j | 486.34 ± 16.61k | 218.63 ± 4.51l | 695.38 ± 16.64m | 510.66 ± 6.64k | 365.32 ± 14.19n | 1906.8 ± 34.43i |
| Linoleic acid (C18:2) | 1548.2 ± 62.18ab | 2242.74 ± 46.62cd | 1191.5 ± 36.66f | 2302.3 ± 79.45c | 1615.41 ± 38.56a | 1481.21 ± 15.94b | 2072.6 ± 17.10e | 1756.7 ± 55.67g | 2175.8 ± 53.73de | 2122.7 ± 58.46e | 1057.4 ± 31.48h | 754.26 ± 34.10i | 908.03 ± 15.68j | 561.17 ± 16.31k | 543.69 ± 1.91k | 1602.8 ± 36.57a |
| Linolenic acid (C18:3) | 147.73 ± 2.57a | 90.94 ± 0.82b | 59.27 ± 1.86c | 76.15 ± 1.61d | 83.20 ± 2.27e | 44.46 ± 0.47f | 84.29 ± 0.62e | 97.18 ± 1.46g | 65.51 ± 0.55h | 87.82 ± 2.47i | 53.20 ± 1.50j | 84.67 ± 1.09e | 63.62 ± 1.31h | 29.95 ± 0.82k | 41.38 ± 0.84l | 64.71 ± 0.87h |
| ΣSFA | 1662.93 ± 58.99 | 2930.02 ± 56.58 | 1594.55 ± 41.02 | 2253.99 ± 66.99 | 2556.36 ± 38.73 | 1838.04 ± 9.90 | 2507.24 ± 71.32 | 1629.43 ± 89.54 | 2388.52 ± 63.39 | 2112.61 ± 100.70 | 1096.78 ± 35.51 | 563.19 ± 26.12 | 776.22 ± 45.06 | 590.64 ± 17.76 | 492.26 ± 24.16 | 2236.76 ± 41.28 |
| ΣUFA | 3773.50 ± 148.01 | 5689.39 ± 140.63 | 3258.79 ± 81.77 | 4622.26 ± 215.58 | 4315.35 ± 84.65 | 3918.35 ± 48.61 | 6021.42 ± 159.91 | 3375.72 ± 116.13 | 4832.90 ± 96.86 | 4227.15 ± 156.70 | 1931.75 ± 59.36 | 1330.08 ± 41.64 | 1868.28 ± 46.19 | 1279.35 ± 30.70 | 1090.75 ± 23.78 | 3977.46 ± 37.44 |
| TFA | 5436.43 ± 207 | 8619.41 ± 197.21 | 4853.34 ± 122.79 | 6876.25 ± 282.57 | 6871.71 ± 123.38 | 5756.39 ± 58.51 | 8528.66 ± 231.23 | 5005.15 ± 205.67 | 7221.42 ± 160.25 | 6339.76 ± 257.40 | 3028.53 ± 94.87 | 1893.27 ± 67.76 | 2644.50 ± 91.25 | 1869.99 ± 48.46 | 1583.01 ± 47.94 | 6214.22 ± 78.72 |
| ΣUFA/ΣSFA | 2.27 | 1.94 | 1.49 | 2.05 | 1.69 | 2.13 | 2.40 | 2.07 | 2.02 | 2.00 | 1.76 | 2.36 | 2.41 | 2.17 | 2.22 | 1.78 |

*Note*. Different letters within the same row are significantly different ($p < 0.05$); ΣSFA = total saturated fatty acids; ΣUFA = total unsaturated fatty acids; TFA = total fatty acid

### *3.3 Principal Component Analysis*

The PCA results of eight fatty acids from 16 avocado accessions were obtained using NTSYS pc 2.1 software and were shown in Figure 3. PCA generalized eight fatty acids to two principal components which accounted for 55.44% of the total variation. The first component F1 explained 33.97% of the total variation and was mainly associated with linoleic acid, palmitic acid, oleic acid, stearic acid, arachic acid, and myristic acid. The second component F2 accounted for 21.47% of the total variation and was fundamentally defined by linolenic acid and palmitoleic acid. The 16 avocado accessions were classified into two groups through PCA, approximately separated the avocado accessions from Hainan province from the avocado accessions from Yunnan province (Figure 4).

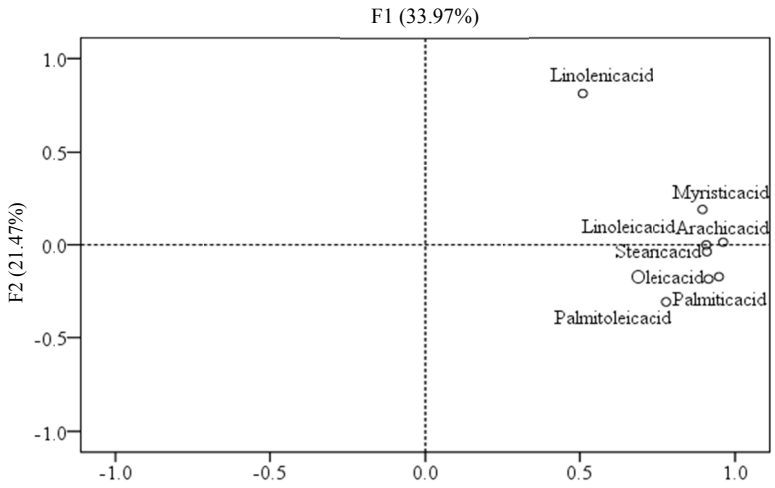


Figure 3. Diagram showing the relationships among eight fatty acids from 16 avocado accessions based on principal component analysis

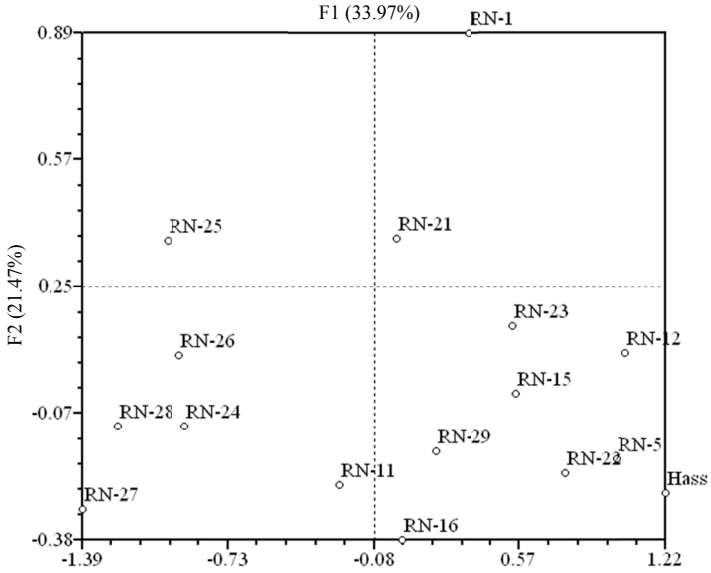


Figure 4. Diagram showing the relationships among the 16 avocado accessions based on principal component analysis using eight fatty acids

*3.4 Cluster Analysis*

Two clusters were evident with similarity coefficient in the dendrogram (Figure 5). As with the results obtained with eight fatty acids, a clear sub-clustering according to geographical origin was observed. Cluster I was composed of five accessions (RN-24, RN-25, RN-26, RN-27, and RN-28) with lower contents for eight fatty acids from Ruili city, Yunnan province. Cluster II comprised two sub-clusters with similarity coefficient. With sub-cluster II-I, eight accessions (RN-1, RN-11, RN-15, RN-16, RN-21, RN-22, RN-23, and RN-29) with intermediate palmitic, oleic, and linoleic acids content clustered together from three districts (Danzhou, Baisha, and Ledong city, Hainan province). In sub-cluster I-II, three accessions (RN-5, RN-12, and Hass) came from Danzhou city, Hainan province, which possessed higher palmitic, oleic, and linoleic acids content.

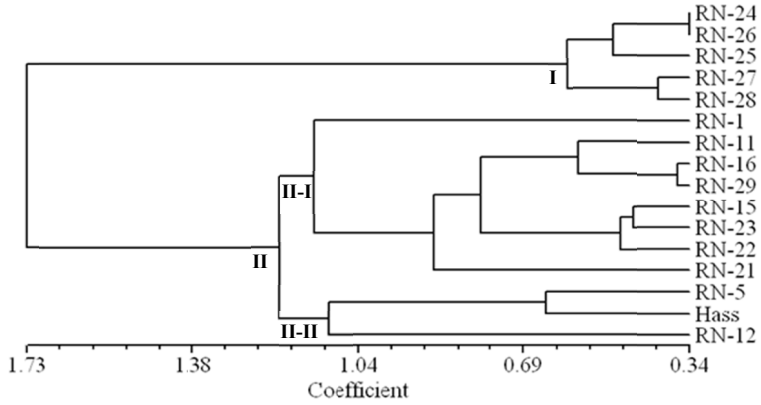


Figure 5. Dendrogram showing the relationships among 16 avocado accessions with eight fatty acids resulting from a UPGMA cluster analysis

The classifications obtained from level of cluster generally grouped the different accessions based on geographic origin in the present study, while the phenomenon was investigated that some accessions from different geographic origins clustered together into the same sub-cluster was still observed. For example, RN-29 from Ledong city of Hainan province and RN-21, RN-22, and RN-23 from Baisha city of Hainan province were clustered with four accessions from Danzhou city of Hainan province, and might have contributed to similarities as Gross-German and Viruel (2013), some avocado accessions from different geographic origins clustering together into the same cluster. One factor contributing to this confounding grouping phenomenon was due to the existence of cultivar popularization between researcher and farmers and/or breeders since the late 1980s. Chinese Academy of Tropical Agricultural Sciences, as non-profit agricultural science research unit, was in duty bound to collect some Chinese local selections from different state farms at different city of Hainan province, and meanwhile, recommend high-quality avocado variety to farmers and/or breeders in neighboring state farms (Ge et al., 2017a).

On the contrary, in the present study, five accessions from Yunnan province, had a distant relation with other accessions from Hainan province, suggesting that they were developed in relatively isolated growing zones and lack of seed exchange. Previous study also demonstrated that the relatively isolated space could result in the diversity and distant phylogenetic relationships of avocado (Galindo-Tovar et al., 2008). Meanwhile, this result demonstrated that commercial avocado accessions were not introduced quickly into Yunnan province for the last 30 years, and some particular useful traits preserved would facilitate their use in improving avocado germplasm and breeding more commercial avocado cultivars, along with the greater economic importance of avocado.

## 4. Conclusions

The present study characterized and evaluated the morphological characteristics, oil content, and fatty acid composition of avocado fruit from 16 accessions collected from the tropical and subtropical regions of China. The results showed significant differences between the different avocado accessions ($p < 0.05$) in terms of their morphological characteristics, oil content, and fatty acid composition. Eight fatty acids were detected, with palmitic, oleic, and linoleic acids being predominant in all avocado accessions, accounting for 78%–91% of the fatty acid compositions. A total of 16 avocado accessions from different geographical origins were distinguished through a PCA scores scatter plot and cluster analysis based on fatty acid profiles. These 16 avocado accessions exhibited different physicochemical characteristics that could be used to classify avocado accessions according to their quality and potential uses.

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