Correlation between Off-flavor and Morphology of Papaya (Carica papaya L.) Fruits

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Authors’ contributions

This work was carried out in collaboration among all authors. Authors AK and CHW designed the study and wrote the first draft manuscript. Author AK conducted all the experiments and performed the statistical analysis. Author CHW contributed to the overall planning, preparing, discussion and review of this research. Author Sobir contributed to the planning, preparing, discussion, review of fruit morphology and correlation analysis. Author DRA contributed on the planning, preparing, discussion, review of off-flavor sensory and correlation analysis. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To investigate the correlation between fruit morphology and off-flavor characteristics which are naturally present in papaya.

Place and Duration of Study: Department of Food Science and Technology (Sensory Laboratory and Food Analysis Services Laboratory), Centre for Tropical Horticulture Study (Chemistry Laboratory) and Indonesian Centre for Rice Research of Indonesian Agriculture Ministry (Flavor Laboratory), between December 2014 and September 2015.

Methodology: Morphology descriptions of 6 papaya varieties, i.e. “Carisya”, “Callina”, “Sukma”, “Merah Delima”, “Burung” and “Bangkok”; off-flavor description using Quantitative Descriptive

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1. INTRODUCTION

Typical distinct flavor of tropical fruits such as in papaya is an important factor for consumer preferences and acceptance [1,2]. Distinctive flavor in papaya is formed through a complex interaction between sugars, organic acids, minerals, and volatile compounds (aroma) [2]. On the other hand, the presence of bitter taste [3] and stinky aroma [4] will reduce consumer acceptance of papaya.

In addition to the distinctive aroma, consumer preferences in selecting and purchasing papayas are also influenced by the morphology of the fruit [5,6], such as the fruit size, peel color, and flesh color. Consumer preference over the fruit size is varied in each region. Papaya fruit with small size and single portion with a weight of 300-500 g is preferred by consumers in Europe [7]. In some countries in Asia; such as Indonesia [8], Philippines [3], and Malaysia [9]; consumers prefer medium sized papaya (650-1600 g). Fruit morphology is also the most commonly used criteria by farmers in distinguishing varieties in the field [10]. Study results of Asudi et al. [10] state that the morphological characteristics of papaya fruit can be used as markers in plant breeding programs to improve the quality of the produced fruit.

One of the research and community development institutions that assesses the quality of papaya in Indonesia is Centre for Tropical Horticulture Study (CENTROHS) at Bogor Agricultural University (IPB). There are three classifications of papaya based on the weight, i.e. small type, medium type and large type. Various superior papaya varieties have been developed by CENTROHS-IPB, for example “Carisya” (small type), “Callina” (medium type), and “Sukma” (large type) [11]. According to the result monitoring of papaya varieties developed by CENTROHS-IPB, small and round shaped papaya showed stronger off-flavor intensity (K. Darma, 1 July 2013, CENTROHS IPB, Indonesia, personal communication). Based on the overall attribute sensory evaluation by Ulrich and Wijaya [4], “Carisya” papaya had a less acceptance than “Sukma” papaya. “Burung” papaya which typically has a round shape and small size was found to be the least accepted. In designing plant breeding programs, knowledge of correlation between fruit characteristics is needed [10].

To the best of our knowledge, there have not been many studies revealing the compounds that certainly contribute to the off-aroma of papaya and the interaction between the attributes of papaya, particularly the off-flavor perception and its correlation to the fruit morphology. Therefore, this study aimed to figure out the correlation between the fruit morphology and off-flavor characteristics of papayas in several papaya varieties from CENTROHS-IPB collection (“Carisya”, “Callina”, and “Sukma”) and other commercial papayas which have similar shapes and sizes to papaya varieties from CENTROHS-IPB collection (“Merah Delima”, “Burung”, and “Bangkok”). The obtained information might help the plant breeder to select the potential varieties to be developed as new superior varieties as well as a consumer reference in choosing the proper fruit in regards to its morphology.

Keywords: Correlation; morphology; off-flavor; papaya; stinky-sour odor.
2. MATERIALS AND METHODS

2.1 Plant Materials

“Carisya”, “Callina”, “Sukma”, “Merah Delima”, “Burung”, and “Bangkok” papayas were utilized in this study. Uniform in size and free of physical defect fruits were harvested at 25-30% of yellow peel in December 2014 from hermaphrodite trees in the IPB experimental garden, CENTROHS-IPB’s nurturing farm, and local farmer’s garden in Bogor and Sukabumi (Indonesia) with the altitude of 250-450 meters above sea level. Each fruit was wrapped in paper, put in cardboard boxes and immediately transported to the laboratory. The fruits were washed and immersed in 2% (w/v) of sodium bicarbonate solution for ±5 min to inhibit anthracnose damage [12], then incubated at ambient temperature (27.5-30.1°C) and 56-79% RH until 85-90% of the peel turned yellow.

2.2 Chemicals

The taste compound standards were obtained from RZBC Group Japan (citric acid) and Shiratori Pharmaceutical Co., Ltd. Japan (caffeine), while the aroma standard solutions were obtained from PT. Firmenich Indonesia (2-methylbutanal, methylbutanoic acid, decanoic acid) and PT. Ogawa Indonesia (butanoic acid). An internal standard (1,4-dichlorobenzene) was purchased from Merck (Germany), and n-alkanes solution (C6-C23) was purchased from Sigma-Aldrich (Germany).

2.3 Fruit Morphology Analysis

Fruit morphological analysis was conducted in accordance to the guidelines from the International Union for the Protection of New Varieties of Plants [13]. Six fruits were used for each papaya sample. Quantitative parameters analyzed were fruit weight, length, diameter, flesh thickness, peel color, and flesh color at ripe stage. Peel and flesh color of ripe fruit were measured using Chroma meter Minolta CR-310 from Konica Minolta (Singapore). The CIE L*a*b* values were then converted to °Hue values to measure color value of fruit peel and flesh at ripe stage using the formula given below [14].

°Hue=arctan (b*/a*)

Where: a*=green-red; b*=blue-yellow; °Hue=0 represents a purple red; °Hue=90° represent yellow; °Hue=180° represent green-blue; °Hue=270° represent blue.

2.4 Off-flavor Sensory Analysis

Off-flavor sensory analysis was performed using Quantitative Descriptive Analysis method (QDA). Panelist selection and training were performed in accordance to ASTM Committee E-18 [15]. Selection stage consisted of questionnaire selection, basic taste recognition test, aroma recognition test, and triangle test. The candidates were those interested in following the sensory evaluation; knew and liked the tested product; had the ability to distinguish sensory attributes; and had the will, seriousness, confidence, and available time to follow the test series. In the next step, selection were based on the ability to identify the basic tastes (100% score), have a minimum score of 70% for aroma recognition test, and correctly discriminate at least 66% out of a total of 24 samples in triangle test.

A total of 12 panelists (22-29 years old, graduate students) who had passed selection stages proceeded to training stages. The panelist training was divided into six sessions with a total time of approximately 30 hours, i.e. the introduction of QDA and off-flavor then introduced with the representative samples, familiarization and discussion of taste and aroma reference standard (R) solution’s scores, familiarization of scaling method using unstructured line, training in the use of unstructured line scale using an R solution, discussion of R concentration in papaya sample representative, and simulation testing of taste and aroma intensity in papaya sample representative.

For the QDA main testing, 2x2x2 cm diced papaya flesh without peel, seeds, and cavity placenta were served to panelists at room temperature. Analyzed sensory attributes were sour and bitter tastes, off-odor and off-flavor-by-mouth (fatty-waxy, sweaty, stinky-sour, and stale-green fecal). Panelists were asked to compare the intensity of each sensory parameter from the sample with the R solution, then put a value on the unstructured line scale of 15 cm. The concentration of taste and aroma R solution are shown in Table 1. The scale value was then converted into a score of 0-60. QDA procedures were performed in accordance to ASTM Committee E-18 [16]. QDA testing was repeated three times.
Table 1. The concentration of R solution of taste and aroma in QDA testing

<table>
<thead>
<tr>
<th>Descriptions</th>
<th>Compounds</th>
<th>Concentrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taste:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sour</td>
<td>Citric acid</td>
<td>0.46 g L⁻¹</td>
</tr>
<tr>
<td>Bitter</td>
<td>Caffeine</td>
<td>0.39 g L⁻¹</td>
</tr>
<tr>
<td>Aroma:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stale-green</td>
<td>2-methylbutanal</td>
<td>3.1 µL + 7 mL propylene glycol</td>
</tr>
<tr>
<td>Sweaty</td>
<td>Methylbutanoic acid</td>
<td>60.1 µL + 7 mL propylene glycol</td>
</tr>
<tr>
<td>Stinky-sour</td>
<td>Butanoic acid</td>
<td>48.5 µL + 7 mL propylene glycol</td>
</tr>
<tr>
<td>Fatty-waxy</td>
<td>Decanoic acid</td>
<td>61.2 µL + 7 mL propylene glycol</td>
</tr>
</tbody>
</table>

2.5 Volatile Compounds Analysis

2.5.1 Samples preparation and extraction of volatile compounds

The sample preparation was performed according to Ulrich and Wijaya [4]. Headspace Solid-Phase Micro-Extraction method (HS-SPME) was employed to extract the volatile compounds. A 10 mL aliquot was pipetted into a 20 mL vial with 2 g NaCl and micro-stirrer. Internal standard (IS), 75 µL of 1,4-dichlorobenzene 1 mg L⁻¹ (w/v, in methanol), was added to the sample and then sealed with a PTFE-lined screw cap. The volatile compounds were extracted using SPME equipped with a DVB/CAR/PDMS fiber (50/30 µm of thickness) from Supelco (Bellefonte, PA). The fiber was exposed to the sample headspace. SPME extraction was performed at 30°C with constant magnetic stirring. A 15 min pre-extraction time and 30 min extraction time were applied, then the SPME fiber was injected into a GC equipped with MSD. Analysis was made in duplicate for each papaya sample.

2.5.2 Gas chromatography - mass spectrometry (GC-MS) analysis

GC-MS analysis was performed in accordance to Ulrich and Wijaya [4]. The GC-MS (GC 7890A and 5975C Inert XL EI/CI MSD) equipped with a polar column (HP-INNOWAX with 0.25 mm of inner diameter, 60 m of length; and 0.25 µm of thickness) from Agilent Technologies, Inc. (Santa Clara, CA) was used. SPME fiber was manually injected to split-less injector and the volatile compounds were thermally desorbed at 250°C. Helium was used as carrier gas at a constant flow rate of 1.0 mL min⁻¹. Detector temperature was 280°C. Oven temperature was held at 45°C for 5 min and then raised to 200°C at 7°C/min and held for 15 min.

Electron impact (EI) mass-spectrometry was performed with 70 eV of electron energy, ion source and interface temperature of 280°C. The mass spectra were collected over the range of m/z 30–300. The target compounds were identified using NIST 05a.L. A series of n-alkanes (C₆–C₂₃) was used to calculate the linear retention index (LRI) of the target compounds then compared to those of published data [17,18]. The relative concentration of target compounds were calculated by comparing the detected area of target compounds by GC-MS to the area of internal standard by GC-MS.

2.6 Statistical Analysis

The data obtained from fruit morphology analysis were analyzed by one-way analysis of variance (ANOVA) followed by Duncan’s Multiple Range Test (DMRT) with 5% significance level. Off-flavor sensory and volatile compounds data then analyzed by Principal Component Analysis (PCA) with Pearson correlation (5% significance level). Correlation analysis between off-flavor characteristics with fruit morphology was determined by Pearson correlation with 5% significance level. PCA was performed using XLSTAT software version 2015.4.01.21244 (Addinsoft). ANOVA and correlation analysis were performed using IBM SPSS Statistics software version 22 (IBM Corp).

3. RESULTS

3.1 Descriptions of Fruit Morphology

Based on the weight, papaya can be classified into small (650 g or less), medium (651-1600 g), and large types (more than 1600 kg) [19]. Statistically, the weight of “Carisya” was not significantly different (P=0.05) to “Burung” and could be classified as the small type. “Callina”, “Merah Delima”, and “Sukma” were classified as medium types while “Bangkok” was included in the large type. Morphologically descriptions of studied papaya are presented in Table 2.
“Carisya” and “Burung” have been determined as short fruits, whereas “Bangkok” and “Sukma” as long ones. “Carisya” showed the smallest diameter. The visual appearance of whole papaya and transverse section of the papaya are presented in Fig. 1. Reddish peel and flesh color of papaya indicated with the Hue degree that close to 0. If the Hue degree close to 90, then peel and flesh color tend to be yellowish [14]. “Carisya” and “Burung” had orangish dominant peel color, while the others had yellower peel color.

The flesh of “Carisya” and “Burung” were thinner than the others. “Merah Delima” and “Bangkok” had thicker flesh. The thicker the flesh, the higher the consumer acceptance [20]. “Carisya”, “Merah Delima”, “Bangkok” had reddish-orange flesh color, while “Callina” and “Sukma” tend to be orangish. “Burung” had yellow flesh color.

### 3.2 Descriptions of Off-flavor Sensory

The results of ODA from each papaya sample are shown in Fig. 2. All observed papaya showed off-flavor characteristics in different intensities. “Carisya” had predominant off-flavor characteristics such as bitter taste, fatty-waxy odor, stinky-sour odor and flavor-by-mouth, sweaty odor and flavor-by-mouth, and stale-green fecal odor and flavor-by-mouth comparing to the other papaya varieties in CENTROHS-IPB collection (Fig. 2a). “Burung” had the most dominant bitter taste, fatty-waxy odor and flavor-by-mouth, as well as stinky-sour odor among the commercially available papaya varieties (Fig. 2b), while “Merah Delima” had dominant sweaty odor and flavor-by-mouth and stale-green fecal odor and flavor-by-mouth. Moreover, the most dominant sour taste showed by “Bangkok”. “Carisya” delivered off-flavor sensory characteristics which were similar to “Burung” and “Merah Delima. “Carisya” had more diverse sensory characteristics than the other papaya in CENTROHS-IPB collection.

### 3.3 The Semi-quantification of Off-flavor Volatiles and Its Correlation to the Aroma Perceptions

The volatiles that were predicted to be responsible for off-flavor perception in papaya were described in Table 3, while the comparison of relative concentration of off-flavor compounds amongst the samples was showed in Fig. 3. There were six targeted volatile compounds obtained from the literatures, but only four which could be detected in the observed papaya, i.e methylbutanoic acid, butanoic acid, hexanoic acid, and octanoic acid. The most abundant off-flavor compounds were found in “Carisya” and “Burung,” with the latter had the most types of off-flavor compounds, i.e. methylbutanoic acid, butanoic acid, hexanoic acid, and octanoic acid. Methylbutanoic acid was not detected in “Carisya” papaya. “Bangkok” had similar volatile composition to “Sukma”, while “Callina” was similar to “Merah Delima”.

The principal component analysis (PCA) (Fig. 4) and correlation analysis (Table 4) were utilized to determine the contribution of off-flavor compounds on the sensory quality. The principal components (PC) accounted for 77.53% (47.21% PC1 and PC2 30.32%) of the total variance in the data set. PCA result matched with the sensory profile showing the off-flavor sensory characteristic of “Carisya” was close to “Burung” and “Merah Delima”. “Callina” and “Sukma” positions were separated from all off-flavor characteristics. As mentioned before, “Callina” and “Sukma” had the lowest off-flavor intensity among others.

### Table 2. Morphology descriptions of papaya

<table>
<thead>
<tr>
<th>Papaya samples</th>
<th>Weight (g)</th>
<th>Length (cm)</th>
<th>Diameter (cm)</th>
<th>Flesh thickness (cm)</th>
<th>Skin color (*Hue)</th>
<th>Flesh color (*Hue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Carisya”</td>
<td>420±25a</td>
<td>16.16±0.76a</td>
<td>7.09±0.64b</td>
<td>2.60±0.37c</td>
<td>58.57±3.24a</td>
<td>43.30±1.80a</td>
</tr>
<tr>
<td>“Callina”</td>
<td>1026±126b</td>
<td>19.89±0.78b</td>
<td>9.59±0.31e</td>
<td>3.16±0.20a</td>
<td>66.75±1.57b</td>
<td>51.39±5.39b</td>
</tr>
<tr>
<td>“Sukma”</td>
<td>1475±158c</td>
<td>27.14±1.47d</td>
<td>11.54±0.85e</td>
<td>3.24±0.46de</td>
<td>70.78±4.92cd</td>
<td>52.99±4.21b</td>
</tr>
<tr>
<td>“Burung”</td>
<td>578±184e</td>
<td>16.10±1.74a</td>
<td>11.24±0.66d</td>
<td>2.67±0.25a</td>
<td>60.88±2.05bc</td>
<td>69.01±1.33c</td>
</tr>
<tr>
<td>“Merah Delima”</td>
<td>1372±371f</td>
<td>23.12±3.01d</td>
<td>10.36±1.25bc</td>
<td>3.87±0.55d</td>
<td>68.47±5.84bc</td>
<td>45.80±1.89d</td>
</tr>
<tr>
<td>“Bangkok”</td>
<td>1863±491d</td>
<td>26.05±3.65c</td>
<td>12.47±1.16a</td>
<td>3.69±0.37cd</td>
<td>73.78±6.46c</td>
<td>45.53±0.81d</td>
</tr>
</tbody>
</table>

*Data for each parameter are an average

*Data followed by different letters in columns are significantly different according to DMRT (P=0.05)
Table 3. Compounds suspected to influence off-flavor perception in fresh papayas

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Aroma descriptions</th>
<th>Detection thresholds (mg L⁻¹)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Methylbutanal</td>
<td>Stale green, fecal [23]</td>
<td>0.001</td>
</tr>
<tr>
<td>Methylbutanoic acid</td>
<td>Rancid butter, sweaty [23]; intense fruity [18]; fruity, cheese [24]</td>
<td>0.001-0.043</td>
</tr>
<tr>
<td>Butanoic acid</td>
<td>Stinky [4]; sour [24]</td>
<td>0.24-4.8</td>
</tr>
<tr>
<td>Hexanoic acid</td>
<td>Stuffy, sour sweet [24]</td>
<td>0.093-10</td>
</tr>
<tr>
<td>Octanoic acid</td>
<td>Waxy, dirty, sweaty, cheesy fatty [21]</td>
<td>0.91-19</td>
</tr>
<tr>
<td>Decanoic acid</td>
<td>Fatty-waxy [25]</td>
<td>2.2-102</td>
</tr>
</tbody>
</table>

*Detection threshold data was obtained from [21,22]

The correlation analysis between off-aroma perception and the concentration of target compounds was showed in Table 4. Butanoic acid had significantly positive correlation (P=0.05) to fatty-waxy odor, stinky-sour odor, and stinky-sour flavor-by-mouth, while octanoic acid had significantly positive correlation (P=0.05) with stinky-sour odor.
Fig. 3. Relative concentration of methylbutanoic acid (■), butanoic acid (■), hexanoic acid (□), octanoic acid (Δ) from the papaya sample

Fig. 4. PCA biplots showing the distribution of off-flavor attributes (■) and off-flavor compounds (▲) in six varieties of papayas (+)  
O=odor, F=flavor-by-mouth

Table 4. Correlation between off-aroma sensory and relative concentration of target compounds

<table>
<thead>
<tr>
<th>Variables</th>
<th>Butanoic acid</th>
<th>Hexanoic acid</th>
<th>Octanoic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatty-waxy odor</td>
<td>0.820</td>
<td>0.659</td>
<td>0.724</td>
</tr>
<tr>
<td>Sweaty odor</td>
<td>0.011</td>
<td>0.261</td>
<td>0.204</td>
</tr>
<tr>
<td>Stinky-sour odor</td>
<td>0.879</td>
<td>0.809</td>
<td>0.876</td>
</tr>
<tr>
<td>Stale green-fecal odor</td>
<td>-0.017</td>
<td>0.001</td>
<td>-0.050</td>
</tr>
<tr>
<td>Fatty-waxy flavor-by-mouth</td>
<td>0.376</td>
<td>0.238</td>
<td>0.322</td>
</tr>
<tr>
<td>Sweaty flavor-by-mouth</td>
<td>0.175</td>
<td>0.400</td>
<td>0.340</td>
</tr>
<tr>
<td>Stinky-sour flavor-by-mouth</td>
<td>0.852</td>
<td>0.779</td>
<td>0.717</td>
</tr>
<tr>
<td>Stale green-fecal flavor-by-mouth</td>
<td>0.378</td>
<td>0.496</td>
<td>0.458</td>
</tr>
</tbody>
</table>

Data in bold prints are significant (Pearson correlation, P=0.05)
Table 5. Correlation between off-flavor characteristics and fruit morphology

<table>
<thead>
<tr>
<th>Variables</th>
<th>Weight</th>
<th>Length</th>
<th>Diameter</th>
<th>Flesh thickness</th>
<th>Skin color</th>
<th>Flesh color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sour taste</td>
<td>0.361</td>
<td>0.425</td>
<td>0.491</td>
<td>0.089</td>
<td>0.351</td>
<td>0.076</td>
</tr>
<tr>
<td>Bitter taste</td>
<td>-0.613</td>
<td>-0.682</td>
<td>-0.064</td>
<td>-0.702</td>
<td>-0.643</td>
<td>0.608</td>
</tr>
<tr>
<td>Fatty-waxy odor</td>
<td>-0.498</td>
<td>-0.555</td>
<td>0.025</td>
<td>-0.683</td>
<td>-0.524</td>
<td>0.563</td>
</tr>
<tr>
<td>Sweaty odor</td>
<td>-0.433</td>
<td>-0.320</td>
<td>-0.817</td>
<td>-0.101</td>
<td>-0.436</td>
<td>-0.438</td>
</tr>
<tr>
<td>Stinky-sour odor</td>
<td>-0.836</td>
<td>-0.873</td>
<td>-0.381</td>
<td>-0.887</td>
<td>-0.838</td>
<td>0.532</td>
</tr>
<tr>
<td>Stale green-fecal odor</td>
<td>0.166</td>
<td>0.056</td>
<td>0.094</td>
<td>0.518</td>
<td>0.065</td>
<td>-0.193</td>
</tr>
<tr>
<td>Fatty-waxy flavor-by-mouth</td>
<td>-0.159</td>
<td>-0.210</td>
<td>0.411</td>
<td>-0.148</td>
<td>-0.214</td>
<td>0.666</td>
</tr>
<tr>
<td>Sweaty flavor-by-mouth</td>
<td>-0.542</td>
<td>-0.489</td>
<td>-0.874</td>
<td>-0.168</td>
<td>-0.559</td>
<td>-0.404</td>
</tr>
<tr>
<td>Stinky-sour flavor-by-mouth</td>
<td>-0.316</td>
<td>-0.398</td>
<td>-0.272</td>
<td>-0.345</td>
<td>-0.413</td>
<td>-0.172</td>
</tr>
<tr>
<td>Stale green-fecal flavor-by-mouth</td>
<td>-0.399</td>
<td>-0.378</td>
<td>-0.443</td>
<td>-0.033</td>
<td>-0.490</td>
<td>-0.139</td>
</tr>
<tr>
<td>Butanoic acid</td>
<td>-0.747</td>
<td>-0.762</td>
<td>-0.506</td>
<td>-0.674</td>
<td>-0.800</td>
<td>0.164</td>
</tr>
<tr>
<td>Hexanoic acid</td>
<td>-0.821</td>
<td>-0.789</td>
<td>-0.691</td>
<td>-0.746</td>
<td>-0.875</td>
<td>0.040</td>
</tr>
<tr>
<td>Octanoic acid</td>
<td>-0.871</td>
<td>-0.830</td>
<td>-0.637</td>
<td>-0.809</td>
<td>-0.911</td>
<td>0.200</td>
</tr>
</tbody>
</table>

Data in bold prints are significant (Pearson correlation, P=0.05)

3.4 Correlation between Off-flavor Characteristics and Fruit Morphology

The correlation between off-flavor sensory, relative concentrations of volatiles, and the fruit morphology are presented in Table 5. There was significant negative correlation (P=0.05) found among the stinky-sour odor to the fruit weight, length, peel color and flesh thickness of papayas. It means those were lighter in weight, shorter in size, thinner in flesh thickness, and more orangish in peel color were closely related to the strong intensity of stinky-sour odor. The strong stinky-sour odor intensity was showed by “Burung” and “Carisya”.

Significantly (P=0.05), hexanoic acid had negative correlation to the fruit weight and the ripe peel color. Octanoic acid also had significantly negative correlation (P=0.05) with fruit weight, length, and ripe peel color. It means the fruit with the lighter in weight, short in size, and papaya varieties with orangish ripe peel color were closely related to the higher concentration of hexanoic acid and octanoic acid. “Carisya” and “Burung” were the papaya with high concentration of hexanoic acid and octanoic acid.

4. DISCUSSION

It has been reported that the idiotype criteria of papaya in Indonesia were the medium size, thick flesh, and yellow-orange peel color [20,26]. Based on the collected data, “Callina”, “Sukma” and “Merah Delima” should be more preferable for consumers in Indonesia comparing to “Carisya” and “Burung”. Regarding the flesh color, Carmen et al. [3] stated that the consumers in Philippines preferred papaya with orange or reddish flesh color as one of the selection criteria, which means the “Carisya”, “Merah Delima”, and “Bangkok” should be more preferable. Considering the consumer preference on those above criteria, “Merah Delima” performance should be the one suited ideally.

Even though “Merah Delima” papaya visually suited the idiotype criteria, it delivered stronger sweaty and stale-green fecal aroma than the other papayas (“Callina” and “Sukma”). Fortunately, the sweaty and stale-green fecal aroma intensity of “Merah Delima” seems still fall in the sensory acceptable range. Moreover, the impact of sweaty and stale-green fecal aroma was not as severe as the bitter taste, fatty aroma, and stinky-sour aroma in shaping the off-flavor perception in papaya. A further study is necessary to clarify this phenomenon.

This study found that “Callina” and “Sukma” had the lowest intensity of off-flavor. This result is in accordance with the study of [4], which showed that the composition and concentration of volatile compounds of “Sukma” were less than “Carisya” and “Burung”. It has been reported that the volatile compounds of “Carisya” were more varied than “Brazil”, “Burung”, “Bangkok”, and “Sukma”. The 20 volatile compounds of “Carisya” were similar to “Burung” [4], where “Burung” is known for its off-odor. This might be the reason of why the “Carisya” which has strong of off-odor located in different quadrant to Sukma which sensorically has no specific off-odor attributes and off-odor volatile components, based on the PCA biplots result (Fig. 4).
The perception of sweaty aroma was allegedly formed as a result from the complex interaction of other compounds (two or more) as stated by Ridgway et al. [27] about off-flavor perception. Study by Larsen and Poll [24], Wijaya et al. [28] found that low concentrations of volatile compounds even below the threshold values also have high impact to aroma perception. A study by Sousa et al. [29] indicated that hexanoic and octanoic acid contributed to sweaty aroma perception in noni fruit. The presence of phenylacetic acid (urine-like), heptanoic acid (sweaty), unknown 1 (human sweat-like) contributed to sweaty aroma perception in rambutan fruit; moreover 2-methylbutanoic acid (sour), hexanoic acid (sweaty), 2-methylpropanoic acid (rancid), octanoic acid (sweaty), butyric acid (vomit/rancid) also found to had sweaty note aroma [30]. In snake fruit [28], 2-methylbutanoic acid (cheesy, unpleasant overripe, sweaty, sour, buttery) and 3-methylpentanoic acid (unpleasant riped cheese, rancid, pungent) were also suspected to contribute to sweaty aroma perception. Other study [23] claimed that methylbutanoic acid (rancid butter, sweaty) was the most responsible for sweaty aroma perception in papaya puree from Sri Lanka. Methylbutanoic acid, hexanoic acid, and octanoic acid could be detected in this study, while the 2-methylbutanoic acid found in papaya cv. Red Maradol [18].

Based on the correlation results (Table 4), the high intensity of butanoic acid was suspected to have close relationship with the strong fatty-waxy and stinky-sour aroma intensity in papaya. The high concentration of octanoic acid was also presumed to have close relationship with the strong stinky-sour aroma intensity. Therefore, it can be presumed that butanoic acid together with octanoic acid contribute to stinky-sour and fatty-waxy aroma. This interaction may occur due to the similar aroma description between octanoic and butanoic acid which are having rancid fat note aroma [31,32]. Butanoic acid known has stinky [4] and sour [24] aroma perception; while octanoic acid has aroma description like waxy, dirty, cheesy fatty [21] and sweaty [21,28]. Butanoic acid and octanoic acid, both were detected simultaneously only in “Burung” and “Carisya”. It might explain the cause of both papaya samples have stronger off-flavor sensory perception than the other samples.

In agreement with the study by Sanimah and Sarip [33], the results showed that papayas with smaller weight were closely related to the higher concentration of volatiles associated with a strong off-flavor perception. They reported that the aroma intensity of papaya var. Sekaki (medium type) was weaker than papaya var. Eksotika (small type).

The negative correlation between morphological characteristics and some aroma compounds were also seen in tomatoes [34,35]. In tomatoes, the quantitative trait loci (QTLs) of aroma located in the same chromosomal locus and adjacent sequences to the QTLs of weight, diameter, and peel color. Blas et al. [36] assumed that the QTLs of size and shape of papaya were homologous to tomatoes, thus the same location of chromosomes and sequences between QTLs were to be suspected to occur also in the papaya. Some QTLs which were located in the same chromosome can be expressed simultaneously [37]. For example, tomatoes [38] which known to have resistance to tomato mosaic virus (ToM V) had yellowish leaves color due to the fact that the location of the yellow color-coding gene locus was close to the locus encoding resistance to ToM V. Therefore, it would be possible to be expressed simultaneously.

The simultaneously expression of QTLs in the papaya was thought to be the basis of an indirect linkage between morphological characteristics and some off-flavor characteristics. The linkage occurred indirectly because QTLs was a segment of a chromosome containing one or several genes associated with variations in quantitative expression of the phenotypic characteristic that was sensitive to environmental conditions [39]. Therefore, it can be alleged that many factors influence the QTLs expression. This result could be applied between papaya varieties and does not apply to diversity in one variety, based on the [13] guidelines. To obtain the correlation between off-flavor characteristics and fruit morphology on diversity within one variety, it necessitates further study.

The correlation indicated the probability of gene loci related to the type of small fruit size adjacent to the locus of aroma compounds genes responsible for off-flavor perception. Results of this study confirmed the results of the study by Saliba-Colombani et al. [34] in tomatoes. This correlation pattern could possibly be applicable to other fruits and vegetables, such as tomatoes. If the correlation result was associated with idiotype criteria of papayas in Indonesia, the
weak intensity of stinky-sour odor might become one of the selection criteria besides the visual appearance. The research on consumer preferences towards papaya indicated that the aroma attribute was one of the consumer preference attributes, but it did not influence the consumer decision when choosing and buying papayas [6]. This also applied when selecting other tropical fruits, such as bananas and watermelons [40]. Esguerra et al. [41] reported that the consumer decision when choosing and buying papayas was most strongly influenced by physical appearance (especially defect-free appearance and attractive peel color), the sweetness level, and the fruit size. This tendency might be caused by the difficulty for the consumers to evaluate the flavor particularly the off-flavor in the whole fruit. However, the selection of papaya by its size seems indirectly related to the intensity of the volatiles which contribute to the off-flavor.

5. CONCLUSION

The off-flavor sensory characteristics in papaya were mostly due to the stinky-sour odor. The octanoic acid was allegedly being able to deliver synergism impact to butanoic acid in giving the perception of stinky-sour odor in the papaya. The stinky-sour odor had negative correlation to weight, length, flesh thickness, and ripe peel color, in accordance to the octanoic acid content that showed negative correlation to fruit weight, length, and ripe peel color. High concentration of octanoic acid and strong intensity of stinky-sour odor were closely related to papaya varieties which had weight 650 g or less, length 16.5 cm or less, flesh thickness less than 3 cm, and orangish ripe peel color. These phenomena might be utilized as selection markers in selecting papaya in the marketplace as well as field selection criteria to breed new superior papaya varieties, i.e. the weight falls around 651-1600 g, flesh thickness larger than 3 cm, and yellowish ripe peel color.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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