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Article

Profiling of Volatile Organic Compounds (VOCs) of Wild Edible Durians from Sarawak, Borneo Associated with Its Aroma Properties

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Abstract: Volatile organic compounds determine the aroma properties of durian, and it is an important factor in durian acceptance by consumers. However, limited information is devoted to volatile organic compounds and aroma in wild edible durians. Therefore, the present study aims to characterize and compare the volatile organic compounds and aroma properties of the indigenous wild edible durians from Sarawak, Borneo. Seven genotypes, namely *Durio dulcis*, *Durio graveolens* (yellow-fleshed), *Durio graveolens* (orange-fleshed), *Durio graveolens* (red-fleshed), *Durio kutejensis*, *Durio oxleyanus*, and *Durio zibethinus* were characterized in this study. Solid phase microextraction combined with gas chromatography-mass spectrometry (SPME GC–MS) was used to detect the volatile organic compounds, while the quantitative descriptive analysis (QDA) method was used to characterize the aroma properties of wild edible durians. A total of 119 volatile organic compounds comprising alcohol, aldehyde, amine, ether, ester, ketone, nitrogen-containing, and sulfur-containing compounds were detected. Ester and alcohol compounds are the most predominant in the composition, especially *D. graveolens* (yellow- and orange-fleshed), and *D. dulcis* possessed three to nine times higher relative amount of ester compounds. PCA clearly classified the wild durians into different groups. Based on the QDA analysis, *D. kutejensis* has the mildest aroma among wild edible durians, while *D. dulcis* perceived a stronger sweet and grassy aroma. Partially Least Square (PLS) regression model analysis indicated a strong relationship between the volatile organic compounds and the aroma intensity perceived by the panelists. These findings could be the major component in the durian industry, paving the way for breeding efforts to create new cultivars that can improve consumers' satisfaction.

Keywords: wild durians; aroma; indigenous; Sarawak; volatile organic compounds

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1. Introduction

Durian (*Durio* sp.) is known as the 'King of Fruits' that grow seasonally in tropical Asia, gaining worldwide attention with its iconic intimidating spiky husk. Besides its admirable flavour, durian is also well-known for the offensive smell that could be overpoweringly unpleasant to those unfamiliar with it. Durian's offensive smell has been described as abominable; an offensive blend of aged cheese and onions with turpentine flavouring [1]. However, the demand for durians has surged as more consumers express interest in this delicacy with a distinctive flavour, making the durian industry more alluring for global importers and exporters. According to Tridge Intelligence [2], Thailand is the biggest exporter of durians, responsible for 46.7% of global exports taking the total to a USD 689.43 million export value. Hong Kong overtook China to take over as the top importer of durians in the same year, with 224.22 million metric tons of imports totalling

USD 717.37 million. China's participation in the Regional Comprehensive Economic Partnership (RCEP), which is the world's largest trade bloc, accounting for 30% of the world's Gross Domestic Product (GDP), has made it easier for China to import fresh fruits from Southeast Asian nations such as Thailand, Malaysia, and Indonesia, the three-leading durian-producing countries [3]. In Malaysia, due to its potential to create new revenue streams for local farmers, durian is regarded as a gold commodity for agriculture in the future [4].

At present, the genus *Durio* consists of approximately 30 species worldwide, of which only ten species produce edible fruits, i.e., *Durio dulcis, Durio graveolens, Durio grandiflorus, Durio kutejensis, Durio kinabaluensis, Durio lowianus, Durio oblongus, Durio oxleyanus, Durio testudinarius*, and *Durio zibethinus* while the remaining species produce either extremely unpalatable (inedible) or arilles fruits [5,6]. The island of Borneo is the center of *Durio* distribution, where Kalimantan has the highest diversity of *Durio* with 18 endemic species [7], while Sabah and Sarawak have 14 and 16 *Durio* species, respectively [8,9]. *Durio zibethinus*, is the most economically significant and widely cultivated [10], while the other edible durian still occurs wild in the tropical forest [5], and some may face the danger of extinction or may already be extinct. In Sarawak, the indigenous edible durians of *D. graveolens* (isu), *D. kutejensis* (nyekak), *D. oxleyanus* (durian daun), and *D. zibethinus* (durian kampung) are domesticated and widely sold at Tamu markets at a good fetching price. These indigenous species could provide a steady source of nutrition and income for local people in rural areas. The other indigenous edible species of *Durio* are still found in the wild, but occasionally they can be found semi-domesticated. The wild edible *Durio* species are equally valuable to *D. zibethinus* as they have the potential as fruits tree crops themselves, although not widely grown near the scale of *D. zibethinus*. Brown [11], Subhadrabandhu and Ketsa [12] and Susilawati et al. [13] stated that these wild *Durio* species have superior quality traits as they have high aesthetic value in terms of their pericarp and aril colours, unique taste and aroma, and some of the species have high disease resistances. These local durians are diverse in shape, taste, and smell, which holds great promise for future domestication.

The aroma of durian was controversial since long ago, which is often described as a fruity, offensive, and onion-like odor due to the presence of volatile esters and sulfur-containing compounds [14]. Fruit aroma is an important factor in durian acceptance by consumers [4]. In fact, taste and aroma influence each other, and aroma is considered a fundamental component of fruit flavour [15]. Fruit aromas differ noticeably due to variations in the composition and content of volatile organic compounds (VOCs). Solid phase microextraction (SPME) is frequently utilized in extracting fruit aromas as it requires less time, is easy, and is solvent-free [15]. In recent years, volatiles emitted from durian were studied by using solid-phase microextraction combined with gas chromatography-mass spectrometry (SPME GC–MS) [4,15,16].

To date, there were numerous studies published on the volatile organic compound profiling of *D. zibethinus* and its cultivars [14,15,17–19]. To the best of our knowledge, information devoted to volatile organic compounds and their aroma on wild edible durians is still limited. The edible wild durian is known to be varied uniquely with its aroma and taste. Furthermore, understanding these VOCs is important because durian is valued for its distinct flavour and aroma. These traits of the wild edible durians need to be explored more, as these might open a new opportunity for the plant breeder to develop new cultivars. Therefore, this study aims to characterize and compare the volatile organic compounds and aroma characteristics of several wild edible durians indigenous to Sarawak, Borneo. The findings of this study can be utilized as the basis for developing new durian cultivars that will increase their favorability and appeal to a larger spectrum of global customers.

2. Materials and Methods

2.1. Sampling Area and Samples Collection

Sampling was conducted during the durian season (from August 2021 to March 2022) in several rural areas within the northeast to central regions of Sarawak, including Bekenu, Niah, Baram, Sibu, and Tatau (Figure 1). The coordinate of each location (Table 1) was marked using Garmin GPS Handheld (GPSMAP79S, Olathe, KS, USA). Twenty-five ripe fruits of *D. dulcis, D. graveolens* (yellow-fleshed), *D. graveolens* (orange-fleshed), *D. graveolens* (red-fleshed), and *D. kutejensis,* and 15 fruits of *D. oxleyanus,* and *D. zibethinus* that dropped naturally were collected. Fruits were selected for uniformity in size and free of diseases and visual defects. The samples were immediately transported to the laboratory and dehusked (the rind was cut open) the same day prior to analyses. Durian pulps that free of visual defects were selected for further analysis.

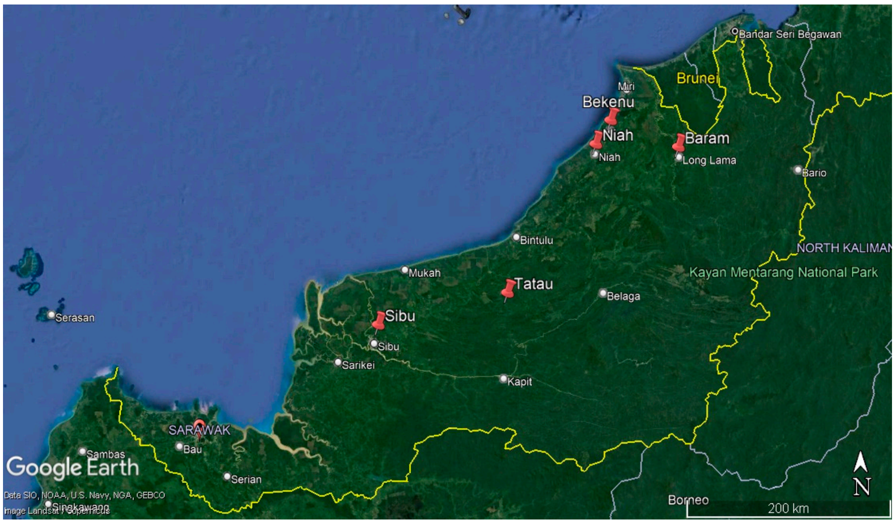

Figure 1. Sampling locations for *Durio* species in Sarawak (Source: Google Earth Pro, 2022).

Table 1. GPS coordinate and sampling location description for wild edible *Durio* species in Sarawak.

Code	Species	Local Name	Locations	Coordinates	Habitat
D1	*D. dulcis*	Tutong	Tatau, Sarawak	N 2° 45′ 47.88″, E 112° 57′ 43.92″	Forest
D2	*D. graveolens* (yellow-fleshed)	Isu kuning	Sibu, Sarawak	N 2° 17′ 16.00″, E 111° 49′ 50.99″	Forest
D3	*D. graveolens* (orange-fleshed)	Isu oren	Niah, Sarawak	N 3° 51′ 43.20″, E 113° 42′ 51.48″	Forest
D4	*D. graveolens* (red-fleshed)	Isu merah	Baram, Sarawak	N 4° 6′ 43.91″, E 114° 22′ 46.42″	Forest
D5	*D. kutejensis*	Nyekak	Bekenu, Sarawak	N 4° 3′ 29.47″, E 113° 50′ 39.09″	Orchard
D6	*D. oxleyanus*	Daun	Baram, Sarawak	N 4° 6′ 43.92″, E 114° 22′ 49.44″	Forest
D7	*D. zibethinus*	Terung iban	Tatau, Sarawak	N 2° 45′ 47.86″, E 112° 57′ 41.90″	Forest

2.2. Fruit Morphology

The morphological characterization of the durian fruit was carried out following the guidelines based on Descriptors Durian (*Durio zibethinus*) by Bioversity International [20]. Six qualitative and four quantitative parameters of the fruit were measured using a ruler, vernier caliper, and laboratory weighing scale.

2.3. Volatile Organic Compounds (VOCs) Analysis

2.3.1. Volatile Organic Compound Extraction Using Solid Phase Microextraction (SPME)

Sample preparation was carried out according to Chin et al. (2007) [19] with slight modifications. 50 g of fresh durian pulps were blended to create homogenate with

100 mL of cooled ice water for 1 min. 10 mL of the blended pulp was transferred into a 30 mL vial together with a magnetic stirring bar and 5 g of sodium chloride. Before the vial was crimped-sealed with 20 mm diameter aluminum seal with Teflon septum, internal standard 100 µL thiophene (10 ppm) was spiked into the sample. The homogenate was kept under constant vigorous stirring at 30 °C for 1 h in a water bath. Then, the SPME syringe was manually inserted into the headspace of the vial with the fiber coating exposed for 30 min. A 50/30 µm divinylbenzene/carboxen on polydimethylsilxane (DVB/CAR/PDMS) fiber was used to extract volatile organic compounds from durian samples.

2.3.2. Volatile Organic Compounds (VOCs) Analysis Using Gas Chromatography-Mass Spectrometry (GC-MS)

The separation was performed using a gas chromatography (GC) system (Agilent 7890A) directly coupled with a mass spectrometer (MS) system of an Agilent 5975C insert MSD with a triple-axis detector as described by Belgis et al. [16]. The analysis was performed in a BP20 (WAX) analytical column (30 m × 0.25 × 0.25 µm film thickness). The injector temperature was held at 240 °C. The injection port was operated at splitless mode with purified helium as the carrier gas flowing at 0.4 mL/min. The oven temperature was set isothermal at 40 °C for 1.5 min, ramped to 240 °C at 50 °C/min, and then held at this temperature for 2 min. The interface temperature was 240 °C, and the ionizing voltage was 70 ev. The MSD Chemstation was used to identify all the peaks in the raw GC chromatogram. A library search was carried out for all the peaks using the NIST/EPA/NIH version 2.0, and the results were combined in a single peak table. Quantification was carried out by comparing peak areas of analytes to that of thiophene added as an internal standard to the samples. Two replications were maintained in this experiment. The relative amount of VOCs was done by comparing the peak areas of the detected VOCs to the peak area of internal standard thiophene. The result was expressed as:

$$\text{Relative amount of VOC} = (\text{Peak area}/\text{Internal standard area}) \times 1000$$

2.4. *Aroma Characterization Using Quantitative Descriptive Analysis (QDA)*

The Quantitative Descriptive Analysis (QDA®) method was used to characterize the aroma of the durian by training the sensory panels and carrying out the analysis according to the set sensory standards (ISO Standard 8586–2:1994). 15 trained panelists were screened and selected (2 sessions) for their sensory ability and trained (4 sessions) for descriptive analysis as described by Voon et al. [18]. The training was held for 1–2 h sessions a week for four weeks until satisfactory discrimination, reproducibility, and concept alignment were achieved. Reference standards are provided to help panelists with specific descriptors (Table 2). A sensory score sheet with 15 cm unstructured scale lines (0–15), each with anchored terms at both ends, was used to indicate the intensity of each attribute by placing a vertical line on the scale. The panels sat in individual booths and were asked to score the sensory properties of Durio species using seven different aroma sensory attributes, i.e., sweet, fruity, sulfury, alcohol, nutty, grassy, and floral. Three sessions were carried out to obtain the mean value for each sample. Panelists were provided water and an unsalted cracker to clear their palates between samples.

Table 2. Aroma sensory attributes that evaluated in the descriptive analysis.

Attributes	Description
Sweet	Aroma associated with ripened honeydew
Fruity	A mixture of aromas associated with fruit, like a banana, melon
Sulfury	Aroma associated with rotten egg aroma
Alcohol	Aroma associated with fermented rice liquid or alcohol
Nutty	The aroma of the nuts
Grassy	The aroma of fresh-cut grass
Floral	Aroma associated with ripened passion fruit or flower

2.5. Statistical Analysis

The data on morphology variables were subjected to a one-way ANOVA following a Tukey test for comparisons of means ($p < 0.05$) using SAS window 9.4. Principal Compo-nent Analysis (PCA) was applied for species mapping based on their volatile organic compounds composition. Partial least squares (PLS) regression model analysis was conducted to study the correlation between volatile organic compounds and aroma characteristics. PCA and PLS analysis were performed using XLSTAT software (Addinsoft, New York, NY, USA).

3. Results and Discussion

3.1. Fruit Morphological Characterization

The seven wild edible *Durio* genotypes were diverse and unique in physical attributes compared to the common cultivars of *D. zibethinus*. This unique look of the wild edible durian makes it easily identified by the locals only by looking at its shape and size or even the spine shape. Among the studied wild durians, there were three genotypes under the species of *D. graveolens*, i.e., *D. graveolens* (isu kuning), *D. graveolens* (isu oren), and *D. graveolens* (isu merah), as they were named by the locals based on its pulp colour (yellow-fleshed, orange-fleshed and red-fleshed, respectively. Under the species of *D. zibethinus*, the local people have addressed this assession as durian kampung, also known as durian Terung iban.

The detailed fruit morphological characteristics are presented in Table 3. The exocarp of the seven genotypes varied from red, green, and yellow. Among the genotypes, the most attractive durian was *D. dulcis*, which the exocarp in red. *Durio kutejensis* and *D. graveolens* (red-fleshed) exhibited yellow exocarp, while *D. graveolens* (yellow- and orange-fleshed), *D. oxleyanus*, and *D. zibethinus* possessed green exocarp. This shows that the wild edible durian genotypes were very attractive compared to the common *D. zibethinus*, which appears green to pale green [21]. *Durio graveolens* species exhibited the most appealing pulp colour, which displays the colour yellow-fleshed, orange-fleshed, and red-fleshed. According to Susilawati et al. [13], the colour of the durian flesh generally has its own appeal in terms of the durian consumption rate. Apart from their aesthetic value, colouration in durian pulp (yellow, orange, and red) indicates that this fruit contains high carotenoids, anthocyanins, and polyphenols which is supported by Tan et al. [4], where Black Thorn possessed the reddish-orange pulp colour with highest total carotenoid content. The presence of carotenoids proves that the fruit has antioxidant properties that would benefit human health, such as eyes, brain, and heart health, as cancer prevention, UV protection, and immune stimulation [22,23].

The wild edible durian genotypes' fruit shapes ranged from globose to obovoid, except *D. kutejensis* in obovate and *D. zibethinus* (terung iban) ovoid fruit shapes. This indicates that the indigenous edible durian from Sarawak exhibits an oblong to globose shape compared to the common durian cultivars, such as common durian cultivars in Malaysia, e.g., D197 (Musang King), D160 (Te Ka) and D175 (Udang Merah), mostly having oval to ellipsoidal [24]. The fruit base shape varied from flat to round, acute, round, and convex, extensively visualized. The Sarawak indigenous durian genotypes possesseda flat to round fruit base shape that is likely to be similar to the common *Durio* species.

The spine shape is an important parameter to look into detail that could differentiate the species or varieties [25], as some local *Durio* species have similar fruit colour, shapes, and sizes. Sujang et al. [26] reported that due to their physical similarity, *D. graveolens* and *D. oxleyanus* were created confusion among locals in Sarawak as both referred to as 'isu'. However, they can be differentiated by their spine shape, where *D. graveolens* have a conical spine shape while *D. oxleyanus* possessed pyramidal with conical and sharply pointed spines. *Durio zibethinus* (Terung iban) exhibited a distantly arranged short spine with the shape of a pointed convex. It was observed that although the fruit size of *D. kutejensis* was smaller, the thickness of the arils (31.18 $\pm$ 5.41 mm) was comparable with the common *D. zibethinus* cultivars. *Durio zibethinus* (Terung iban) also possessed a significantly higher thickness at 30.65 ± 3.73 mm. This is contradicted by the *D. dulcis*, where the fruit size was significantly larger ($p < 0.05$) yet exhibited lesser aril thickness (5.75 ± 2.19 mm). Most of the indigenous edible durian was not easy to be opened as some of the appearances of the carpel are slightly distinct and indistinct such as *D. dulcis*, *D. graveolens* (yellow-, orange-, and red-fleshed) and *D. oxleyanus*. The hardest fruit to split is *D. dulcis*, which requires a cross-section method of splitting.

Table 3. Morphological variabilities of seven wild edible durian genotypes from Sarawak.

Species	***D. dulcis***	***D. graveolens* (Yellow-Fleshed)**	***D. graveolens* (Orange-Fleshed)**	***D. graveolens* (Red-Fleshed)**	***D. kutejensis***	***D. oxleyanus***	***D. zibethinus***
							
	10 cm	6 cm	6 cm	6 cm	6 cm	8 cm	10 cm
Fruit shape	Globose to obovoid	Globose to obovoid	Globose to obovoid	Globose to obovoid	Obovate	Globose	Ovoid
Base shape	Flat to round	Flat to round	Flat to round	Flat to round	Acute	Convex	Round
Pericarp colour (visual)	Red to dark red	Green	Green	Yellow to green	Yellow	Green	Pale green to green
Carpel easiness of splitting	Difficult	Difficult	Difficult	Easy	Easy	Difficult	Easy
Spine shape	Conical	Conical	Conical	Conical	Pyramidal	Pyramidal with conical and sharp points	Pointed convex
							
Aril colour (visual)	Pale yellow	Yellow	Orange	Red	Yellow	Pale yellow	Pale yellow
Fruit length (cm)	14.50 ± 2.66 [a]	12.10 ± 2.39 [b]	11.35 ± 1.53 [b]	11.15 ± 1.55 [b]	12.78 ± 0.75 [ab]	12.05 ± 1.46 [b]	12.95 ± 0.60 [ab]
Fruit width (cm)	15.90 ± 2.81 [a]	13.12 ± 1.60 [bc]	13.28 ± 1.06 [bc]	13.1 5± 1.53 [bc]	11.20 ± 0.82 [c]	12.75 ± 1.16 [bc]	13.70 ± 1.53 [ab]
Fruit weight (g)	865.1 ± 383.1 [a]	559.0 ± 239.0 [b]	489.3 ± 104.8 [b]	504.0 ± 199.0 [b]	469.1 ± 94.5 [b]	541.7 ± 115.8 [b]	719.6 ± 99.6 [ab]
Thickness of aril (mm)	5.75 ± 2.19 [e]	24.08 ± 3.422 [b]	15.96 ± 3.17 [cd]	21.27 ± 4.98 [bc]	31.18 ± 5.41 [a]	12.31 ± 4.78 [d]	30.65 ± 3.73 [a]

The values are presented as the means ± standard deviation. Different superscript alphabets in the same row indicate differences at $p < 0.05$ (ANOVA, Tukey's test).

3.2. Compositions of Volatile Organic Compounds (VOCs) of Sarawak Wild Edible Durians

A total of 119 VOCs were identified in the genotypes, comprising 37 esters, 32 alcohols, 13 ketones, 10 ethers, 10 sulfur-containing compounds, 8 nitrogen-containing compounds, 5 aldehydes, and 4 amines. The composition of the VOCs in the seven genotypes of wild edible durians varies, as shown in Figure 2, and these differences determine the durians' flavour and quality. The volatile organic compounds showed a great variation in different genotypes and ranged from 24 compounds in *D. graveolens* (Yellow-fleshed) and *D. zibethinus* (Terung iban) to 33 compounds in *D. oxleyanus*. The numerous VOCs that are present in durian contribute to its distinct scents. Ester compound was the highest percentage composition ranged 20% to 40%, followed by the alcohol compound ranged 8% to 36%. Most of the genotypes showed large composition with the ester compound followed by the alcohol compound except in *D. kutejensis* and *D. zibethinus* (Terung iban), as both genotypes have a higher composition of the alcohol compound followed by the ester compound. A total of 10 esters were identified in *D. dulcis*, *D. graveolens* (orange-fleshed), and *D. oxleyanus*. Followed by *D. graveolens* (yellow-fleshed) (9), *D. graveolens* (red-fleshed) (8), and with the least esters (5) in *D. kutejensis* and *D. zibethinus* (Terung iban). This contradicts the common durian cultivars of D2, D24, D101, MDUR78, CHUK, D88, D168, D175, D197, and D200, which possessed higher composition of sulfur compounds

(9 to 15 compounds) as reported by Tan et al. [4], Xiao et al. [15], Voon et al. [18], and Chin et al. [19]. However, these wild edible durians exhibited the least composition of sulfur with 1 to 5 compounds. The present findings are in agreement with the volatile organic composition in the local durians of *D. kutejensis* (Batuah), which was predominantly by ester compounds (11), followed by alcohols (4), aldehydes (3), sulfurs and ketones (2) [16]. The presence of the nitrogen-containing compound was not detected in *D. dulcis* and the three genotypes of *D. graveolens*. Amine compounds only present, one to two compounds in *D. graveolens* (orange-fleshed), *D. kutejensis*, and *D. oxleyanus*.

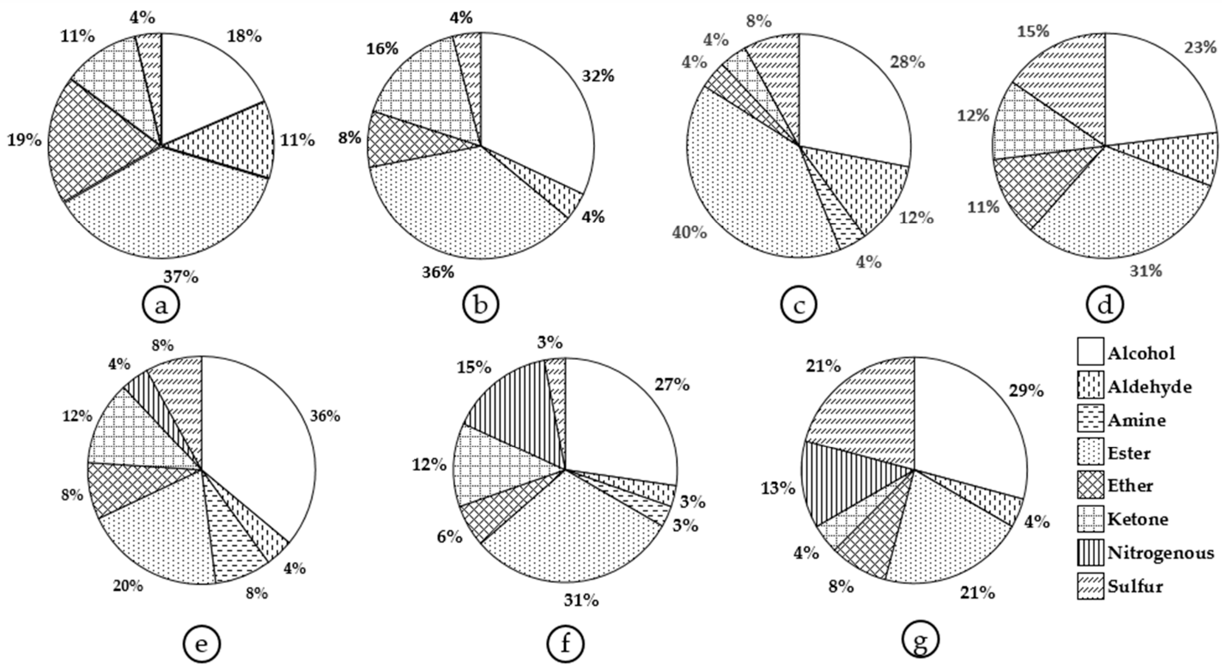

Figure 2. The composition of chemical classes in the seven durian genotypes of Sarawak; (**a**) *Durio dulcis*, (**b**) *Durio graveolens* (yellow-fleshed), (**c**) *Durio graveolens* (orange-fleshed), (**d**) *Durio graveolens* (red-fleshed), (**e**) *Durio kutejensis*, (**f**) *Durio oxleyanus*, and (**g**) *Durio zibethinus* (Terung iban).

3.3. Volatile Organic Compounds (VOCs) of Sarawak Wild Edible Durians

The identified volatiles and their relative amount in the respective genotypes are summarized in Table 4. The identified volatile organic compounds in durian genotypes were consistent with Tan et al. [4], Xiao et al. [15], Voon et al. [18], and Chin et al. [19]. and a few new compounds were identified for the first time in this study, as this is the first detailed profiling of all the wild edible durians in Sarawak.

Esters were the major compounds with almost 50% or surpass half of the relative amounts of VOCs in all the studied genotypes, except in *D. graveolens* (red-fleshed) (24.53%), *D. kutejensis* (8.83%) and *D. oxleyanus* (27.71%). Each genotype had different types of dominant esters, which may contribute to each genotype's unique aroma characteristics. This can be seen in *D. graveolens* (yellow-fleshed) that butanoic acid, heptyl ester was the dominant ester compound, and *D. graveolens* (orange-fleshed) was the butanoic acid, butyl ester. Both of the compounds were described as giving fruity (pear, pineapple) and chamomile-like odor [27] (Table 4). Propanoic acid, 2-methyl, 3-methylbutyl ester compound can only be found in the three genotypes of *D. graveolens* that contributed to the sweet and fruity aroma. *Durio kutejensis* have the least amount of ester compounds, which was supported by Belgis et al. [16], where the lai cultivars from Indonesia (*D. kutejensis)* contained few esters, which explained the less intense fruity and sweet aroma. The study by Chin et al. [19] showed that ethyl-2-methylbutanoate is the major ester present in all (D101, D2, and D24) Malaysian durian cultivars, and this was in accordance with the present finding in *D. zibethinus* (Terung iban).

Table 4. List of volatile organic compounds (VOCs) and their chemical classes, odorant description, CAS number, and retention time (RT) in seven genotypes of wild edible *Durio* species in Sarawak obtained using the headspace SPME GC-MS method.

	Compounds	Odor Description [27,28]	CAS	RT	Relative Amount in the Headspace						
					D1	D2	D3	D4	D5	D6	D7
Alcohol											
A1	Propyl mercaptan	Sulfuraceous	107–03−9	1.51							21.14
A2	4-Octanol, 2-[(tert.butyloxycarbonyl) amino]		1000164–64−5	1.62		16.91					
A3	1-Pentanol, 4-amino-		927–55−9	1.74						6.94	
A4	4-Pentanol, 2-[(tert.butyloxycarbonyl)amino]		1000164–64−4	1.85							3.51
A5	Ethanol	Vinous odor	64–17−5	1.98	157.26				81.66	27.63	48.57
A6	2-Hexanol	Fatty, terpenic	626–93−7	2.21					21.14		
A7	1-Propanol, 2-methyl-	Sweet, musty	78–83−1	2.88	181.00			368.38			
A8	1-Butanol, 3-methyl-	Whiskey	123–51−3	3.43		458.54	553.44	553.12	52.39		
A9	2-Furanmethanol, tetrahydro-, acetate	Fruity, ethereal	637–64−9	3.47						8.59	
A10	1-Pentanol	Mild alcohol odor	71–41−0	3.60					15.86		
A11	Ethanol, 2-(vinyloxy)-		764–48−7	3.77							9.90
A12	1,2-Propanediol, 3-methoxy-		623–39−2	3.85							36.57
A13	1-Hexanol	Fruity, alcohol	111–27−3	3.91					116.83		
A14	3-Hexanol, 2-methyl-	Flavouring agent	617–29−8	3.99		270.50	160.50				
A15	4-Heptanol, 2,6-dimethyl-	Flavouring agent	108–82−7	4.32			175.26				
A16	2,3-Butanediol	Creamy, buttery	513–85−9	4.45		55.34		71.93	72.61		
A17	2-(Ethylsulfonyl)ethanol	Meaty flavor	513–12−2	4.45						87.87	
A18	1-Deoxy-d-altritol		68832–18−8	4.64	32.06						
A19	Ethanol, 2-(1-methylethoxy)-	Mild, ethereal	1000153–20−8	4.69				9.01			
A20	2-Furanmethanol	Warm, oily, burnt	5405–41−4	4.75	143.14	78.77	92.30	75.61	137.94	27.59	
A21	4,5-Octanediol, 2,7-dimethyl-	Floral	1000153–20−8	4.94		61.16	32.52				
A22	2-Propanol, 1-(1-methylethoxy)-		3944–36−3	5.35							9.51
A23	Phenylethyl Alcohol	Rose-like floral	60–12−8	5.37		40.20	22.12				
A24	Trimethylsilyloxy)ethoxy]ethoxy]ethoxy] ethoxy]ethoxy]ethoxy]ethanol		1000131–70−7	5.39				21.42			
A25	4-Amino−1-butanol		13325–10−5	5.49						21.09	
A26	(3-Methyl-oxiran−2-yl)-methanol		1000194–22−9	5.94			43.47			17.35	
A27	1,6-Dideoxy-l-mannitol		68832–20−2	6.06					10.15		
A28	2-Hexadecanol		14852–31−4	6.21		32.04				11.53	
A29	2-Eicosanol		4340–76−5	6.42						9.24	
A30	Ethanol, 2-[2-(2-butoxyethoxy)ethoxy]-	Mild odor	143–22−6	6.52	29.57						
A31	2-Dodecanol	Flavouring agent	10203–28−8	7.12					6.25		
A32	Ethanol, 2-bromo-	Sweet burning	540–51−2	7.37							1.67
	Total				**543.03**	**1013.46**	**1079.61**	**1099.47**	**514.83**	**217.83**	**130.87**
Aldehyde											
B1	Propanal, 2-methyl-	Pungent, floral	78–84−2	1.44	68.66		73.03				
B2	Furan−3-carboxaldehyde, 2-methoxy-		1000132–11−1	5.14	30.56						
B3	DL-Arabinose		29493–06−9	5.19				13.46			
B4	3-(1-Ethoxyethoxy)-butyraldehyde		116616–30−9	5.28			9.68				
B5	5-Hydroxymethylfurfural	Chamomile	67–47−0	6.79	224.71	144.09	109.13	26.88	53.74	65.38	31.79
	Total				**323.93**	**144.09**	**191.84**	**40.34**	**53.74**	**65.38**	**31.79**
Amine											
C1	1-Butanamine, N-methyl-	Ammonia-like	110–68−9	1.34					7.43		
C2	3-Methoxyamphetamine		17862–85−0	1.37			12.09				
C3	Ethylamine	Fishy	75–04−7	5.93						37.94	
C4	Dimethylamine	Fishy	124–40−3	7.21					8.33		
	Total				**0.00**	**0.00**	**12.09**	**0.00**	**15.76**	**37.94**	**0.00**

Table 4. *Cont.*

	Compounds	Odor Description [27,28]	CAS	RT	Relative Amount in the Headspace						
					D1	D2	D3	D4	D5	D6	D7
Ester											
D1	Propanoic acid, 2-methyl-, methyl ester	Fruity (apple)	144–62−7	1.88				37.65			
D2	Propanoic acid, 2-methyl-, ethyl ester	Fruity (Citrus)	97–62−1	2.17	271.07	663.51	531.72			80.86	
D3	(R)-(-)-Methyl 3-hydroxybutyrate		3976–69−0	2.28							6.94
D4	Butanoic acid, ethyl ester	Fruity (pineapple)	109–21−7	2.54				33.04			
D5	Butanoic acid, 3-methyl-, ethyl ester	Strong, Fruity	108–64−5	2.65			13.63				
D6	Butanoic acid, 2-methyl-, ethyl ester	Fruity, wine	7452–79−1	2.66	1234.71	43.53		78.80	20.23	163.64	317.99
D7	Butanoic acid, butyl ester	Fruity (pear)	109–21−7	2.79			2898.95				
D8	Propanoic acid, 2-methyl-, butyl ester	Strong, fresh	2050–01−3	2.82				247.48			
D9	Propanoic acid, 2-methyl-, 2-methylpropyl	Sweet, estry	97–85−8	2.83						37.29	
D10	Butanoic acid, heptyl ester	Chamomile-like	5870–93−9	2.85		3656.76					
D11	Butanoic acid, 2-methyl-, propyl ester	Fruity, sweet	37064–20−3	3.04	50.43				5.50	43.14	121.35
D12	Butanoic acid, 2-methylpropyl ester	Fruity (melon)	2445–67−2	3.14			45.71				
D13	2-Butenoic acid, ethyl ester, (E)-	Pungent, sharp	623–70−1	3.16	64.09						
D15	Propanoic acid, 2-methyl-, 3-methylbutyl ester	Sweet, Fruity	2050–01−3	3.24		209.08	315.87	81.95			
D16	2-Butenoic acid, 2-methyl-, ethyl ester	–	55514–48−2	3.40	329.89						
D17	Heptanoic acid, methyl ester	Sweet, Berry	108–82−7	3.63				18.91			
D18	Hexanoic acid, propyl ester	Ether-like	626–77−7	3.70						3.10	
D19	Butanoic acid, 2-hydroxy−2-methyl-		32793–34−3	3.76	68.28						
D20	Hexanoic acid, 2-methylpropyl ester	Cocoa-like	105–79−3	3.84		105.49	97.92				
D21	Butanedioic acid, 2,3-bis(acetyloxy)-		51591–38−9	3.97	47.91						
D22	Octanoic acid, ethyl ester	Cocoa odor	106–32−1	4.11	37.20	16.73					
D23	Hexanoic acid, ethyl ester	Sweet, fruity	123–66−0	4.14					13.06		
D24	2,4-Hexadienoic acid, methyl ester, (E,E)-	Sweet, fruity	689–89−4	4.15						9.98	
D25	Pentanoic acid, 2-hydroxy−4-methyl-, ester	Fruity, musty	40348–72−9	4.32		111.55					
D26	n-Caprylic acid isobutyl ester	Fruity, floral	5461–06−3	4.56		65.50	23.68				
D27	Arsenous acid, tris(trimethylsilyl) ester		116616–30−9	4.99				12.54			
D28	.beta.-Alanine, trimethylsilyl ester		5269–40−9	4.99							6.22
D29	Butanoic acid, 3-hydroxy-, ethyl ester	Grape odor	5405–41−4	5.18			5.83				
D30	10-Bromodecanoic acid, ethyl ester		55099–31−5	5.25					21.80		
D31	Acetic acid, hydroxy-, ethyl ester		623–50−7	5.27							10.51
D32	Pentanoic acid, 1-methylethyl ester	Fruity	18362–97−5	5.27						13.68	
D33	Methoxyacetic acid, 2-pentadecyl ester		1000282–05−1	5.40	17.39						
D34	Succinic acid, (4-methoxyphenyl) ester		029493–06−9	5.55			46.98				
D35	alpha.-Aminooxy-propionic acid, ethyl ester		5766–86−9	5.62					13.40	9.23	
D36	N-Hydroxycarbamic acid		28564–83−2	5.76				40.78			
D37	Propanoic acid, ethyl ester	Odor reminiscent	105–37−3	6.35	26.37	40.05	41.91			23.87	
	Total				**2147.34**	**4912.20**	**4022.20**	**551.15**	**73.99**	**384.79**	**463.01**
Ether											
E1	Ethylene oxide	Ethereal	75–21−8	1.20		43.97					
E2	Ethene, ethoxy-	Ethereal odor	109–92−2	1.46	26.20						
E3	Pentane, 1-methoxy-		97–62−1	1.93				35.01			
E4	L(-)-Fucose, tetramethyl ether		1000332–75−0	2.40	36.98						
E5	Octaethylene glycol monododecyl ether		1000214–51−8	5.30				17.29			
E6	Oxirane, (propoxymethyl)-		3126–95−2	5.93					25.26		
E7	Methyl 6,8-dodecadienyl ether		1000130–99−9	6.41	22.92						
E8	1,4,7,10,13,16-Hexaoxacyclooctadecane		1000194–22−9	6.97	2.50	21.30	51.06	63.17	6.62	8.58	3.04
E9	15-Crown−5		33100–27−5	7.21	10.08						3.74
E10	2,3-Epoxybutane		3266–23−7	7.22						5.34	
	Total				**98.68**	**65.27**	**51.06**	**115.47**	**31.88**	**13.92**	**6.78**

Table 4. *Cont.*

Compounds		Odor Description [27,28]	CAS	RT	Relative Amount in the Headspace						
					D1	D2	D3	D4	D5	D6	D7
Ketone											
F1	2-Acetyl−3-methylpyrazine	Nutty odor	23787–80−6	3.61						9.88	
F2	5-Hepten−2-one, 6-methyl-	Fruity	5461–06−3	3.85				160.02			
F3	Acetoin	Bland, woody,	513–86−0	3.87						60.44	
F4	2-Cyclohexen−1-one, 2-methyl-		1121–18−2	4.67	11.37						
F5	3-Octen−2-one, 4-methoxy-	Earthy, spicy,	24985–52−2	4.82		100.92					
F6	2-Cyclopenten−1-one, 2-hydroxy-	Caramellic type	10493–98−8	5.06					14.64		
F7	2H-Imidazol−2-one, 1,3-dihydro−4-methyl-		60–12−8	5.08				22.31			
F8	3,4-Dihydroxy−5-methyl-dihydrofuran−2-one		1000193–83−1	5.17					8.46		
F9	2-Propanone, 1-(1,3-dioxolan−2-yl)-		767–04−4	5.27		26.11					
F10	4H-Pyran−4-one, 3,5-dimethyl-		19083–61−5	5.55	44.83						
F11	2-Hydroxy−3-pentanone	Flavouring agent	5704–20−1	5.94		69.57					
F12	4H-Pyran−4-one, 3,5-dihydroxy−6-methyl-		28564–83−2	6.14	125.38	87.64	54.20	43.78	27.41	43.78	17.65
F13	6-Propyltetrahydro−2H-thiopyran−2-one		201991–53−9	6.68						5.44	
	Total				**181.580**	**284.24**	**54.20**	**226.11**	**50.51**	**119.54**	**17.65**
Nitrogen-containing compound											
G1	Pyrazine, 2-ethyl−5-methyl-	Nutty odor	13360–64−0	4.08						9.12	
G2	Pyrazine, 3-ethyl−2,5-dimethyl-		13360–65−1	4.24						487.27	
G3	1H-Imidazole, 2-ethyl-		20185–22−2	4.33							9.97
G4	Imidazole, 1,4,5-trimethyl-		1000222–86−6	4.66						14.99	
G5	Oxime-, methoxy-phenyl-	Fishy odor	13360–65−1	4.88						7.60	4.46
G6	3-Methyl−3-isopropyldiaziridine		24476–95−7	5.74					34.25		
G7	Tetramethylhydrazine	Ammonia-like	6415–12−9	5.74						33.71	
G8	Isoxazolidine, 4-ethyl−2,5-dimethyl-, cis-	Burnt-type odor	56701–01−0	5.74							15.53
	Total				**0.00**	**0.00**	**0.00**	**0.00**	**34.25**	**552.69**	**29.96**
Sulfur-containing compound											
H1	Acetaldehyde	Ethereal	75–07−0	1.18	52.51			46.43	29.20		
H2	Ethanethiol	Overpowering	75–08−1	1.25							24.74
H3	1-Propanethiol, 2-methyl-	Sulfurous	513–44−0	1.51		89.50	91.30	91.30			
H4	Propanethioic acid, 2-methyl-, S-ethyl ester		72437–68−4	3.12				36.72			
H5	Diethyl disulfide	Roasted onion	110–81−6	3.31				53.74		19.41	258.84
H6	Disulfide, ethyl 1-methylethyl		53966–36−2	3.67							47.44
H7	Methyl pentyl disulfide	Sulfurous	72437–68−4	3.72			4.47				
H8	Trisulfide, diethyl	Alliaceous,	3600–24−6	4.45							42.25
H9	1,2,4-Trithiolane, 3,5-dimethyl-	Sulfurous	23654–92−4	4.76							37.51
H10	Divinyl sulfide	Evil smelling	627–51−0	6.35					34.22		
	Total				**52.51**	**89.50**	**95.77**	**228.19**	**63.42**	**19.41**	**410.78**

The second dominant VOCs was the alcohol compounds which account for 12% in *D. zibethinus* (Terung iban) to 48.92% in *D. graveolens* (red-fleshed). The three genotypes of *D. graveolens* have the highest relative amount to alcohol compounds, which were two times higher than the other genotypes. However, *D. kutejensis* had more diverse alcohols, although alcohols total relative amount of *D. kutejensis* was the third lowest among the seven genotypes. Several alcohols were only found in different durian genotypes and might also contribute to the nuanced aroma differences between the wild *Durio* species and common cultivars of *D. zibethinus.* 2−Furanmenthanol (burnt aroma) was the primary alcohol compound in *D. graveolens* (red-fleshed) and *D. dulcis*, but it does not present in *D. zibethinus* (Terung iban).

Sulfur−containing compounds were generally responsible for the distinct strong onion-like odor in durian fruit. Results revealed *D. zibethinus* (Terung iban) exhibited two (*D. graveolens*−red fleshed) to twenty (*D. oxleyanus*) times higher relative amout (37.66%) of sulfur-containing compounds. Diethyl disulfide and ethanethiol present in *D. zibethinus* (Terung iban), were also present in the *D. zibethinus* cultivars reported by Tan et al. [4] and Chin et al. [19]. Together with disulfide, ethyl 1−methylethyl, trisulfide, diethyl, and 1,2,4−Trithiolane,3,5−dimethyl−compounds found in this study might serve as character impact compounds in *D. zibthenus* that contributes to its strong sulfur note compared to other wild *Durio* species. A previous study by Belgis et al. [16] shows that the lai was less diverse sulfurs than durian cultivars, supporting this present work. The other genotypes, except for *D. zibethinus,* account for only 1.37% in *D. oxleyanus* to 10.15% in *D. graveolens* (red−fleshed). Moreover, it is found that 1−propanethiol, 2−methyl−compound is only present among the three genotypes of *D. graveolens*. Divinyl sulfide in *D. graveolens* (red-fleshed) in the least amount has been detected in several foods, especially onions.

Other compounds, such as nitrogen-containing compounds, ketones, aldehydes, amines, and ethers, were also detected in these wild edible durians. However, they only present in small amounts, or some are not in some genotypes. Nitrogen-containing compounds only was found in *D. oxleyanus* (38.91%), *D. kutejensis* (4.09%), and *D. zibetinus* (Terung iban) (2.75%). Ketones, aldehydes, amines, and ether compounds account for less than 10% of the relative amounts of the VOCs, or some of them are not detected in each genotype. There was no previous study that has reported on the presence of nitrogen-containing compounds in durians. Ketone and aldehyde compounds were reported to be present in durians by Tan et al. [4], Belgis et al. [16] and Voon et al. [18]. From the odor description in Table 4, aldehyde, ether, and ketone generally give fresh, fruity, floral, and ethereal odors, while amine and nitrogen-containing compounds possess ammonia-like, burnt-like, and fishy odor [27,28].

3.4. Principal Component Analysis (PCA) of the Volatile Organic Compounds (VOCs)

To explore the relationship between the volatile organic compounds profiles of samples from the various durian genotypes, principal component analysis (PCA) was performed to identify the grouping of the genotypes based on the correlation matrix. The finding revealed the first two principal components (PCs), PC1 (33.32%) and PC2 (29.20%), together accounted for 62.93% of the data variance. The result of PCA reveals that the seven genotypes were classified into five groups which can be seen in Figure 3. From the case projection on the factor plane (PC1 versus PC2), the PC1 axis distinguished *D. dulcis* that constituted a cluster on the positive side, while *D. graveolens* (yellow-fleshed), *D. graveolens* (orange−fleshed), *D. graveolens* (red-fleshed), *D. kutejensis*, *D. oxleyanus*, and *D. zibethinus* (Terung iban) spread at the negative side of PC1 axis.

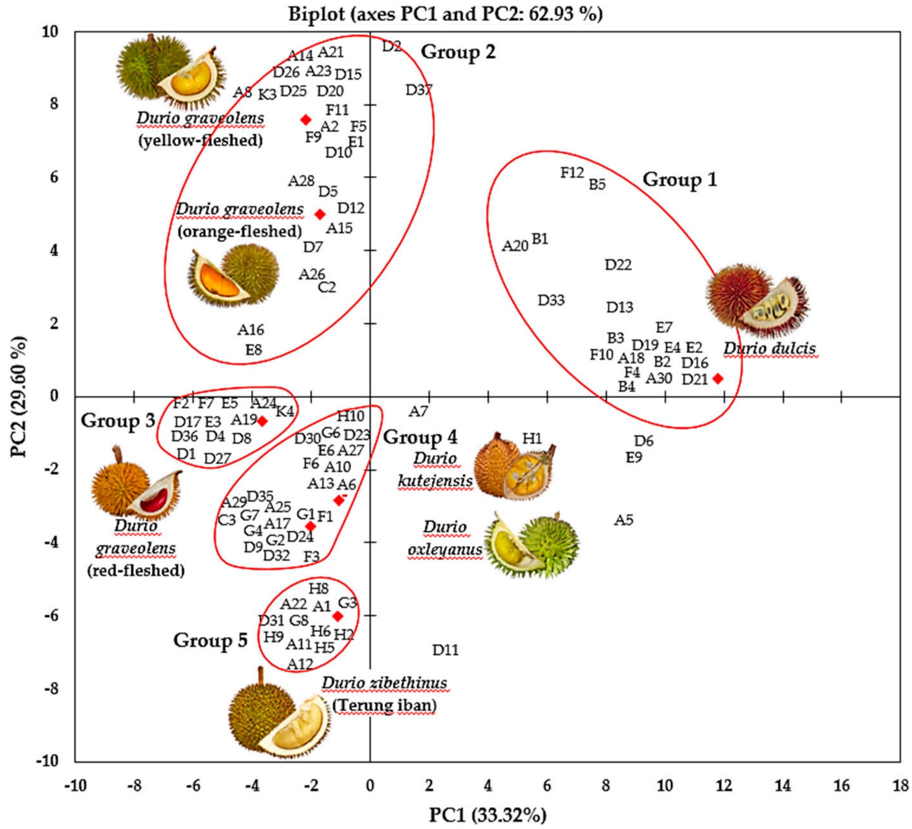

Figure 3. Prinicpal Component Analysis (PCA) biplot of wild edible durians in Sarawak. The code of the volatile organic compounds was referred to in the list of the volatile organic compounds in Table 4.

Group 1 consists of *D. dulcis* alone on the positive side of the PC1 axis, as it has a high amount of aldehyde, ketone, and ether compounds. The ester compounds such as (E)–2-butenoic acid, ethyl ester; 2-methyl-2-butenoic acid, ethyl ester; 2-hydroxy-2 -methyl-butanoic acid, methyl ester; [R-(R*, R*)]-2,3-bis(acetyloxy), butanedioic acid; octanoic acid, ethyl ester, and methoxyacetic acid, 2-pentadecyl ester compounds were only present in *D. dulcis*. The presence of (E)-2-butenoic acid, ethyl ester, and octanoic acid, ethyl ester, which describe as having a pungent and sulfury odor, respectively, could explained the most ill-smelling of all *Durio* species that can be smelled for miles as stated by Soegeng-Reksodihardjo [8]. Moreover, *D. dulcis* also recorded the highest amount of 2-Furanmenthanol compound among the genotypes, where the compound gave a burnt odor. The two genotypes of *D. graveolens*, yellow-fleshed and orange-fleshed, were grouped on the positive side of PC2 (Group 2). This group was characterized as both genotypes having a similar presence of compounds such as alcohol, ester, and a small amount of ether, ketone, and sulfur but amine is not present in the yellow-fleshed genotype. Butanoic acid, heptyl ester, and butanoic acid, butyl ester had the highest relative amount in yellow- and orange-fleshed genotypes, which give a fruity odor [27,28].

Durio graveolens (red-fleshed), *D. kutejensis*, *D. oxleyanus*, and *D. zibethinus* located in negative PC2, were grouped into three groups. *Durio graveolens* (red−fleshed) in Group 3 was characterized by a mixture of mild aroma from alcohol, ester, and sulfur compounds and high relative amount of ketone and ether. The presence of ketone, ester, and ether compounds gives the durian a floral, fruity, and sweet odor. *Durio kutejensis* and *D. oxleyanus* grouped in Group 4 as they both perceived almost the same compounds. Alpha.−Aminooxy-propionic acid and ethyl ester compounds were only present in both genotypes of this group. However, *D. oxleyanus* has a high relative amount of nitrogen-containing compounds, such as tetramethylhydrazine and 2−ethyl−5-methyl-pyrazine, which might be responsible for the ammonia-like and nutty odor, respectively. This supports the report by Soegeng-Reksodihardjo [8] as they stated that *D. oxleyanus* was slightly fragrant but had a very tasty aril with a strong odor. *Durio zibethinus* alone, in Group 5, was characterized by a higher amount of sulfur-containing compound than other genotypes. Ethanethiol, diethyl disulfide, disulfide ethyl 1-methylethyl, trisulfide diethyl, and 3,5-dimethyl-1,2,4-Trithiolane were reported to be responsible for overpowering and roasty odor [28]. Thiol and sulfur were generally the most odorous aroma compounds and were found to be relatively high in all durian clones [19].

3.5. Sensory Analysis by Quantitative Descriptive Analysis (QDA)

The sensory evaluation was evaluated by 15 trained panelists, and the profiles of the 7 genotypes of wild edible durians are shown in Figure 4. The QDA result revealed that the genotypes varied in the intensity of sweet, fruit, sulfur, alcohol, nutty, grassy, and floral aroma attributes. The analysis showed that *D. dulcis* was characterized by the strongest sweet and grassy aroma. The panelist perceived *D. kutejensis* and *D. oxleyanus* as mild aroma durian. The research by Belgis et al. [16] found that *D. kutejensis* generally has a milder aroma. The three genotypes in *D. graveolens*, yellow-fleshed and orange-fleshed, have strong fruity and sweet aromas, while red-fleshed have a strong nutty aroma; however, the *D. graveolens* perceived an intense alcohol aroma compared to the other wild edible durian genotypes. *Durio graveolens* was characterized by the highest relative amount of alcohol compounds. Gamero et al. [29] stated that depending on the synergistic effect with other flavour−active compounds, the high amount of alcohol compounds can exhibit floral, fruity, or herbal aromas The panellists determined the intensities of the sulfur aroma of the seven genotypes in descending order: *D. oxleyanus, D. kutejensis, D. dulcis, D. graveolens* (yellow-fleshed), *D. graveolens* (red-fleshed), *D. graveolens* (orange−fleshed), and *D. zibethinus* (Terung iban). *Durio zibethinus* (Terung iban) possessed a strong sulfur aroma, similar to common durian cultivars [18,19]; however, it has a weak floral, grassy, and nutty aroma. This is most likely due to *D. zibethinus* (Terung iban) sensing the most sulfur-containing compounds (Table 4), such as ethanethiol, diethyl disulfide, ethyl 1-methylethyl disulfide, diethyl trisulfide, and 3,5-dimethyl-1,2,4-trithiolane.

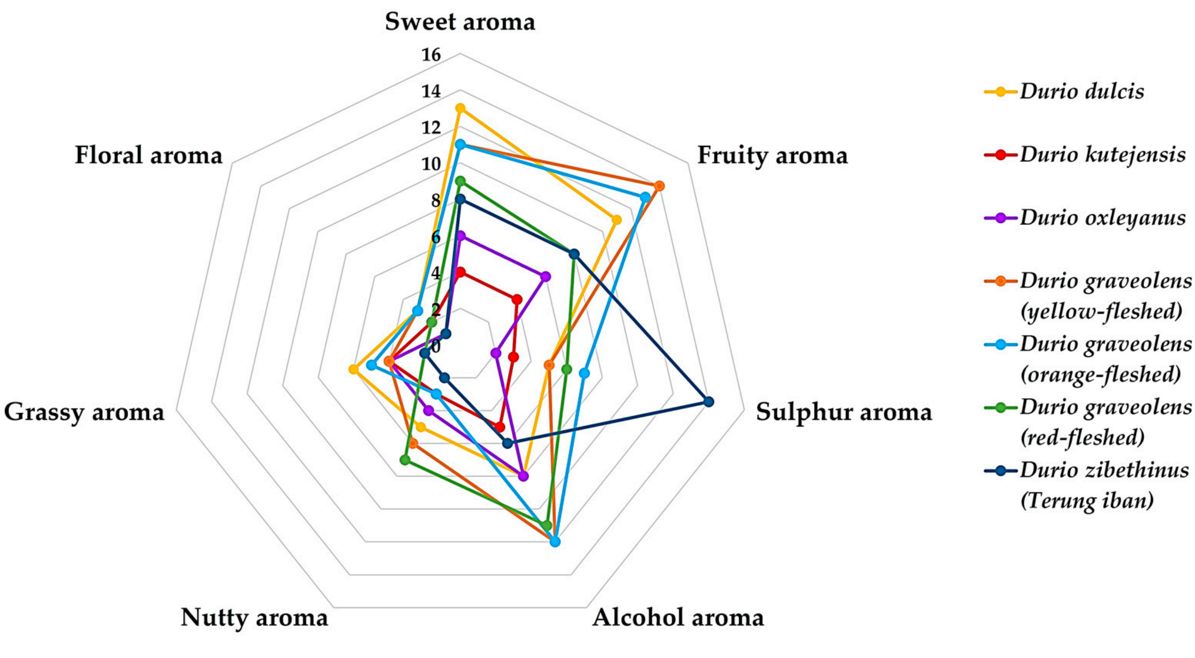

Figure 4. Spider-web of seven aroma sensory attributes in seven wild edible durians in Sarawak.

3.6. Correlation Analysis between Volatile Organic Compounds (VOCs) and Aroma Profiles

Partial least square (PLS) regression model analysis has been previously used to determine the relationship between the sensory and volatile profiling of durian [18], peach [30], and melon [31]. Thus, in this study, PLS model was performed to correlate the sensory scores with the volatile organic compounds of the wild edible durians that were detected using chromatography. The sensory data set was defined as the y-variable, and the amount of the volatile organic compounds was determined as the x-variables under the hypothesis that the volatile organic compound profile might primarily influence the sensory perception of durian. As can be seen in the PLS loading biplot (Figure 5), the seven genotypes were grouped into four following quadrants.

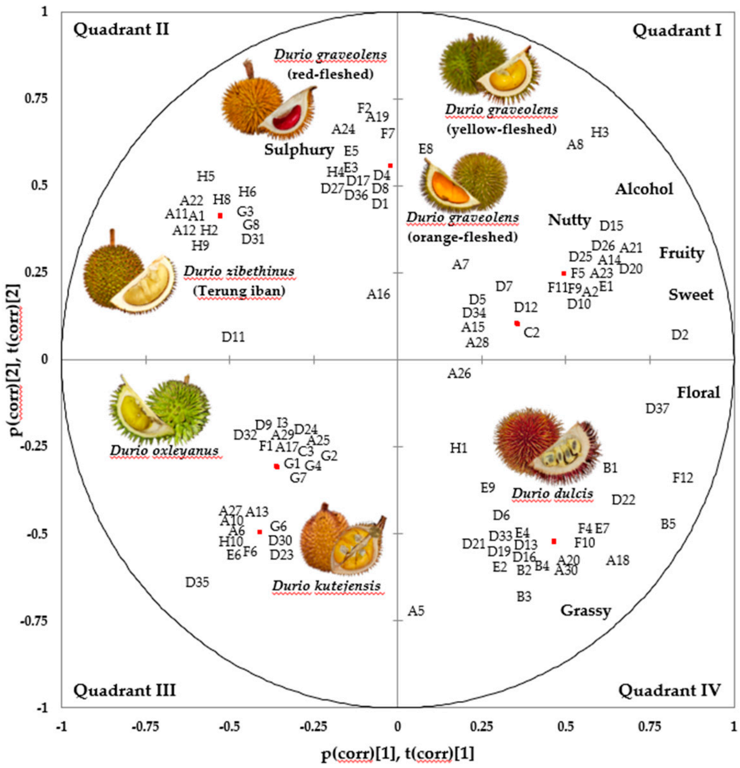

Figure 5. Partial least square (PLS) biplot of seven genotypes of wild edible durians.

This result was confirmed with QDA data in which *D. graveolens*, yellow-fleshed and orange-fleshed, in Quadrant I, grouped as having alcohol, nutty, fruity, and sweet aroma as there is the presence of various volatile organic compounds. The compounds such as 3-methyl−1-butanol, 2-methyl−1−propanethiol strongly correlate to alcohol aroma (0.887 and 0.920, respectively), 2-methyl−3-hexanol and 2,7−dimethyl−4,5−octanediol strongly correlate with fruity aroma (0.789 and 0.779, respectively) and 1,4,7,10,13,16-hexaoxacyclooctadecane strongly correlate with nutty aroma (0.785), where all of these compounds might contribute to the various aroma in *D. graveolens*, yellow and orange-fleshed. This PLS result grouped *D. graveolens* (red-fleshed) and *D. zibethinus* (Terung iban) in Quadrant II because both genotypes had presented of high relative amount of diethyl disulfide (H5), and it was a strongly positive correlate (0.890) (Table 5) with sulfur aroma. Some sulfur-containing compounds, such as ethanethiol, ethyl 1−methylethyl disulfide, diethyl trisulfide and 3,5−dimethyl−1,2,4-trithiolane were correlated strongly to the sulfury aroma, with correlation value between 0.890 to 0.901. *Durio kutejensis* and *Durio oxleyanus* grouped together in Quadrant III due to their mild aroma, which was proven in the QDA correlation. *Durio dulcis* (Quadrant IV) was shown to have a different aroma profile than other genotypes. The aldehyde compounds, 2-methyl-propanal (B1) and 5-hydroxymethylfurfural (B5), which were described as having green and floral odor were strongly correlated (0.759 and 0.852, respectively) with grassy aroma (Table 5). These compounds were probably separating *D. dulcis* from other genotypes. Butanoic acid, 2-methyl-, ethyl ester (D6), an ester compound, has a high amount in *D. dulcis* but did not correlate well with a fruity aroma. This is in agreement with the findings by Belgis et al. [16] and Voon et al. [18], where the concentration of butanoic acid, 2−methyl−, ethyl ester did not increase linearly with an increase in the intensity of fruity aroma.

Table 5. Correlation coefficients between the volatile organic compounds detected from the seven genotypes of wild durians and its sensory description.

Compounds	Sweet	Fruity	Sulfur	Alcohol	Nutty	Grassy	Floral
Propyl mercaptan	−0.121	−0.137	**0.901**	−0.442	−0.560	−0.559	−0.560
1−Butanol, 3−methyl−	0.387	0.573	−0.010	**0.887**	0.509	−0.134	0.527
Ethanol, 2−(vinyloxy)−	−0.121	−0.137	**0.901**	−0.442	−0.560	−0.559	−0.560
1,2−Propanediol, 3−methoxy−	−0.121	−0.137	**0.901**	−0.442	−0.560	−0.559	−0.560
3−Hexanol, 2−methyl−	0.447	**0.799**	−0.043	0.720	0.217	0.230	0.623
4,5−Octanediol, 2,7−dimethyl−	0.440	**0.789**	−0.050	0.708	0.240	0.215	0.612
2−Propanol, 1−(1−methylethoxy)−	−0.121	−0.137	**0.901**	−0.442	−0.560	−0.559	−0.560
Phenylethyl Alcohol	0.442	**0.792**	−0.048	0.712	0.233	0.220	0.616
Propanal, 2-methyl−	0.678	0.537	0.005	0.288	−0.120	**0.759**	0.650
5−Hydroxymethylfurfural	0.746	0.628	−0.255	0.251	0.233	**0.852**	0.744
Propanoic acid, 2-methyl−, ethyl ester	0.663	**0.905**	−0.112	0.728	0.209	0.532	**0.778**
Propanoic acid, 2−methyl−, 3−methylbutyl ester	0.474	**0.762**	0.036	**0.836**	0.127	0.213	0.637
Hexanoic acid, 2−methylpropyl ester	0.467	**0.813**	−0.006	0.752	0.102	0.291	0.650
Acetic acid, hydroxy−, ethyl ester	−0.121	−0.137	**0.901**	−0.442	−0.560	−0.559	−0.560
.alpha.−Aminooxy-propionic, ethyl ester	**−0.861**	**−0.787**	−0.581	−0.616	−0.326	0.065	−0.409
Propanoic acid, ethyl ester	0.612	**0.796**	−0.271	0.665	0.132	0.686	0.645
1,4,7,10,13,16−Hexaoxacyclooctadecane	0.041	−0.018	−0.095	0.467	**0.785**	−0.555	0.013
4H−Pyran−4-one, 2,3−dihydro−3,5–6-methy−	**0.791**	0.630	−0.313	0.372	0.497	0.728	0.736
Isoxazolidine, 4−ethyl−2,5−dimethyl−, cis−	−0.121	−0.137	**0.901**	−0.442	−0.560	−0.559	−0.560
Ethanethiol	−0.121	−0.137	**0.901**	−0.442	−0.560	−0.559	−0.560
1−Propanethiol, 2−methyl−	0.440	0.639	0.002	**0.920**	0.542	−0.123	0.542
Diethyl disulfide	−0.151	−0.199	**0.890**	−0.393	−0.439	−0.690	−0.633
Disulfide, ethyl 1−methylethyl	−0.121	−0.137	**0.901**	−0.442	−0.560	−0.559	−0.560
Trisulfide, diethyl	−0.121	−0.137	**0.901**	−0.442	−0.560	−0.559	−0.560
1,2,4−Trithiolane, 3,5−dimethyl−	−0.121	−0.137	**0.901**	−0.442	−0.560	−0.559	−0.560

Significant correlations at the $p < 0.05$ level are marked in bold.

4. Conclusions

A total of 119 volatile organic compounds were identified in the wild edible durians, with ester (20–40%) and alcohol (18–36%) compounds being the most predominant. This is probably the main cause of the distinct aroma patterns in wild durians compared to the well-known cultivars of *D. zibethinus*. PCA clearly classified the wild durians into different groups. *Durio dulcis*, *D. graveolens* (yellow-, and orange-fleshed), *D. kutejensis*, and *D. oxleyanus* possessed two to ten-fold higher levels of ester compounds compared to *D. zibethinus* (Terung iban). Ester compounds are generally linked to pleasant smell and are often responsible for the fruity aroma. *Durio zibethinus* (Terung iban) possessed a higher relative amount of sulfur-containing compounds, where responsible for the onion-like pungent odor. A higher relative amount of ketone and ether in *D. graveolens* (red-fleshed) gives the durian a floral, fruity, and sweet odor while *D. oxleyanus* with higher nitrogen-containing compounds, is characterized by a nutty smell. Based on the QDA analysis, *D. kutejensis* has the mildest aroma among wild edible durians, with a less intense sulfury, fruity, and sweet aroma. *Durio dulcis* perceived a stronger sweet and grassy aroma, while *D. graveolens* had an intense alcohol aroma compared to the other wild edible durian genotypes. The partial least square (PLS) correlation coefficient confirmed the relationship between the aroma and volatile organic compounds of the durian species. This finding is an approach to identifying the potential of these wild edible durians, which will aid in breeding efforts to produce new durian cultivars and improve the sensory quality of the fruit to increase consumer satisfaction.

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provided critical feedback, and helped shape the research, analysis, and manuscript. All authors have read and agreed to the published version of the manuscript.

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References

1. Small, E.; Catling, P.M. Blossoming treasures of biodiversity: 18. Durian—A smell from hell but a taste from heaven. *Biodiversity* **2006**, *6*, 33–38. [CrossRef]
2. Tridge. Available online: https://www.tridge.com/intelligences/durian/ (accessed on 5 December 2022).
3. Nikkei Asia. Available online: https://asia.nikkei.com/Economy/Trade/China-s-durian-boom-sparks-ASEAN-alarm-over-mega-trade-deal (accessed on 5 December 2022).
4. Tan, X.Y.; Misran, A.; Cheong, K.W.; Daim, L.D.J.; Ding, P.; Dek, M.S.P. Postharvest quality indices of different durian clones at ripening stage and their volatile organic compounds. *Sci. Hortic.* **2020**, *264*, 109169. [CrossRef]
5. Lim, T.K. *Edible Medicinal and Non-Medicinal Plants*; Springe: Dordrecht, The Netherlands, 2012; pp. 550–583.
6. Ghazalli, M.N.; Hashim, M.H.; Besi, E.E.; Mat-Esa, M.I.; Zaini, A.Z.; Saranum, M.M.; Latiff, A. *Durio gerikensis* (Malvaceae), a new arilless *Durio* from Hulu Perak, Malaysia. *Phytotaxa* **2022**, *543*, 21–30. [CrossRef]
7. Uji, T. Keanekaragaman jenis dan sumber plasma nutfah *Durio* (*Durio* spp.) di Indonesia. *Bul. Plasma Nutfah* **2005**, *11*, 28–33.
8. Soegeng-Reksodihardjo, W. The species of *Durio* with edible fruits. *Econ. Bot.* **1962**, *16*, 270–282. [CrossRef]
9. Abang Mohd Mokhtar, A.P. The Taxonomy of *Durio* in Sarawak (Malaysia). M. Sc. Thesis, University of Reading, Reading, UK, 1991.
10. O'Gara, E.; Guest, D.I.; Hassan, N.M. Botany and production of durian (*Durio zibethinus*) in Southeast Asia. In *Diversity and Management of Phytophthora in Southeast Asia*; Drenth, A., Guest, D.I., Eds.; Australian Centre for International Agricultural Research: Cranberra, Australia, 2004; pp. 180–186.
11. Brown, M.J. *Durio, a Bibliographic Review*; International Plant Genetic Resources Institute: New Delhi, India, 1997; 196p.
12. Subhadrabandhu, S.; Ketsa, S. *Durian: King of Tropical Fruit*; Daphne Brasell Associates: Wellington, New Zealand, 2001; 194p.
13. Susilawati, S.; Sabran, M. Morphological characterization of local durian [*Durio Zhibetinus*] from Katingan Regency. *Bul. Plasma Nutfah* **2018**, *24*, 107–114.
14. Peng, J.S.M. Volatile esters and sulfur compounds in durians & a suggested approach to enhancing economic value of durians. *Malays. J. Sustain. Agric.* **2019**, *3*, 5–15.
15. Xiao, Z.; Niu, M.; Niu, Y. Comparative study on volatile compounds and taste components of different durian cultivars based on GC-MS, UHPLC, HPAEC-PAD, e-tongue and e-nose. *Molecules* **2022**, *27*, 1264. [CrossRef] [PubMed]
16. Belgis, M.; Wijaya, C.H.; Apriyantono, A.; Kusbiantoro, B.; Yuliana, N.D. Volatiles and aroma characterization of several lai (*Durio kutejensis*) and durian (*Durio zibethinus*) cultivars grown in Indonesia. *Sci. Hortic.* **2017**, *220*, 291–298. [CrossRef]
17. Lu, Y.; Fong, A.S.Y.L.; Chua, J.Y.; Huang, D.; Lee, P.R.; Liu, S.Q. The possible reduction mechanism of volatile sulfur compounds during durian wine fermentation verified in modified buffers. *Molecules* **2018**, *23*, 1456. [CrossRef] [PubMed]
18. Voon, Y.Y.; Hamid, N.S.A.; Rusul, G.; Osman, A.; Quek, S.Y. Characterisation of Malaysian durian (*Durio zibethinus* Murr.) cultivars: Relationship of physicochemical and flavour properties with sensory properties. *Food Chem.* **2008**, *103*, 1217–1227. [CrossRef]
19. Chin, S.T.; Nazimah, S.A.H.; Quek, S.Y.; Man, Y.C.; Rahman, R.A.; Hashim, D.M. Analysis of volatile compounds from Malaysian durians (*Durio zibethinus*) using headspace SPME coupled to fast GC-MS. *J. Food Compos. Anal.* **2007**, *20*, 31–44. [CrossRef]
20. Bioversity International. *Descriptors for Durian (Durio zibethinus Murr.)*; Bioversity International: Rome, Italy, 2007; 75p.
21. Salma, I.; Hasran, M.; Awaluddin, M.N. *Durian Clones*; Malaysian Agricultural Research and Development Institute (MARDI): Serdang, Malaysia, 2018; 104p.
22. Eggersdorfer, M.; Wyss, A. Carotenoids in human nutrition and health. *Arch. Biochem. Biophys.* **2018**, *652*, 18–26. [CrossRef] [PubMed]
23. Kandylis, P. Phytochemicals and antioxidant properties of edible flowers. *Appl. Sci.* **2022**, *12*, 9937. [CrossRef]
24. Abdul Aziz, Z. *Managing Durian Orchards in Malaysia*; Universiti Putra Malaysia Press: Selangor, Malaysia, 2020; 129p.
25. Ketsa, S.; Wisutiamonkul, A.; Palapol, Y.; Paull, R.E. The durian: Botany, horticulture, and utilization. *Hortic. Rev.* **2020**, *47*, 125–211.

26. Sujang, G.B.; Ramaiya, S.D.; Kalu, M.; Saupi, N.; Lee, S.Y. Characterization of Indigenous Durians (*Durio graveolens* and *Durio oxleyanus*): Relationship of Physicochemical and Aroma Properties with Sensory Profiling. In Proceedings of the 2nd International Scientific Conference on Indigenous Crops, Kuching, Malaysia, 21–24 September 2022.
27. The Good Scents Company Information System. Available online: http://www.thegoodscentscompany.com/index.html (accessed on 3 December 2021).
28. Burdock, G.A. *Fenaroli's Handbook of Flavor Ingredients*; CRC Press: Sydney, Australia, 2016; 2159p.
29. Gamero, A.; Dijkstra, A.; Smit, B.; de Jong, C. Aromatic potential of diverse non-conventional yeast species for winemaking and brewing. *Fermentation* **2020**, *6*, 50. [CrossRef]
30. Liu, H.; He, H.; Liu, C.; Wang, C.; Qiao, Y.; Zhang, B. Changes of sensory quality, flavor-related metabolites and gene expression in peach fruit treated by controlled atmosphere (CA) under cold storage. *Int. J. Mol. Sci.* **2022**, *23*, 7141. [CrossRef] [PubMed]
31. Valverde, M.F.; Sánchez-Palomo, E.; Alises, M.O.; Romero, C.C.; González-Viñas, M.A. Volatile and sensory characterization of la mancha trujillo melons over three consecutive harvests. *Foods* **2021**, *10*, 1683. [CrossRef] [PubMed]