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Profiling of physicochemical properties, volatile and non-volatile compounds, and sensory preferences of three durian (*Durio zibethinus* L.) varieties in Peninsular Malaysia

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Abstract

Durian (*Durio zibethinus* L.) is a tropical fruit extensively cultivated in Southeast Asia, especially Malaysia, Indonesia, Thailand, and the Philippines. “D200”, “D197”, and “D24” are the three most famous durian varieties in Malaysia. However, there is a notable disparity in their market prices, leading to the assumption that higher-priced varieties possess superior quality. Fruit quality is an important parameter that determines consumer preference. Therefore, the present work aimed to investigate the differences in the three popular Malaysian durian varieties (“D200”, “D197”, and “D24”) from different geographical regions, particularly physicochemical properties, volatile and non-volatile compounds, and consumer preference, in order to verify the accuracy of the assumption. The results of the analysis showed significant differences ($p < 0.05$) in physicochemical properties and non-volatile compounds among different durian varieties. Meanwhile, no significant difference ($p > 0.05$) was found between the same durian varieties from different geographical regions, except for colour chromaticity a^*, titratable acidity, and firmness. On the other hand, GC-MS results revealed that durians contained 18 volatile compounds including five sulphur compounds, five esters, four alcohols, one ketone, and three other compounds. Hedonic test results revealed that the sensory preference scores rated by panellists had no significant difference ($p > 0.05$) for the three different varieties, except for surface colour. Overall, panellists preferred Pahang “D200”. Principal component analysis explained 64.30% of the total variation, with PC1 and PC2 accounting for 39.00 and 25.30%, respectively. In conclusion, physicochemical characteristics, and volatile and non-volatile compounds of the three durian varieties showed differences, and consumers preferred all the three durian varieties, with “D200” scoring the highest, followed by “D197” and “D24”.

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Introduction

Durian (*Durio zibethinus* L.) is a tropical and climacteric fruit believed to be native to Borneo, Sumatra, and Peninsular Malaysia. It grows in warm and humid climates of the equatorial tropics. It is extensively cultivated in Southeast Asia, especially Malaysia, Indonesia, Thailand, and the Philippines. Since November 2007, Malaysia has obtained approval for the market route to China for frozen durian in pulp and paste forms. Later, in 2018, Malaysia was permitted to export frozen durian in whole fruit form to China. The increasing demand for durian in China is one factor driving Malaysia’s durian market. In addition, due to its high nutritional content and widespread acceptance by various products, including ice creams, pastries, and snacks, durian has grown in popularity among the Asian countries (Samad, 2022).

Durian is also Malaysia’s most widely grown crop, accounting for 41% of the total planted fruit crop area, over 73,000 hectares. The six main

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varieties that are identified to have high commercial value and in high demand are "D24" (Sultan), "D160" (Musang Queen), "D168" (Hajah Hasmah), "D197" (Musang King), "D200" (Black Thorn), and "D99" with two considered premium, namely "D197" and "D24" (Sazili, 2018). In recent years, "D200" has been gaining popularity in both local and international markets. The major planting areas of durian are in Pahang and Johor. Meanwhile, Penang is famous with durian cultivar "D200". Therefore, these states constituted the sampling locations for the durian samples in the present work.

In Malaysia, "D200," "D197," and "D24" are prominent in the export market. However, there is a notable disparity in their market prices. Despite the assumption that higher-priced varieties correspond to superior quality, limited research has explored the underlying differences in quality among these varieties. This raises questions about the quality of these durian varieties, necessitating an investigation into the factors influencing consumers, and the objective quality attributes of each variety. Therefore, the present work aimed to explain the variation of three popular Malaysian durian varieties in terms of fruit quality and consumer preference. The present work could be potentially used as a reference for uninitiated merchants and consumers for durian selection, especially for exportation purposes.

Materials and methods

Materials

Three durian varieties that are popular in local and international markets, namely "D200", "D197", and "D24" were selected as the study samples, and purchased from local durian orchards located in Pahang, Penang, and Johor, Malaysia. According to suppliers, ripe durian fruits of uniform size and no visual defects were collected and transported to Universiti Putra Malaysia on the same day of harvest. Fresh durians were kept at room temperature for firmness tests and sensory evaluation. Meanwhile, for other analyses, the durians were de-husked and kept in the freezer.

Physicochemical properties

Colour

The pulp colour of each durian variety was measured using a Minolta chromameter (Model CR-300, Osaka, Japan). The surface of durian pulp was aimed by the chromameter receptor during measurement. Six readings were obtained for each sample. The mean reading of each sample was then expressed in L^*, a^*, and b^*, which represent lightness, redness, and yellowness, respectively.

pH and titratable acidity

The pH and titratable acidity of each durian variety was determined according to Voon *et al*. (2007a). The pH of durian pulp was determined using an electrode pH 700 meter (Eutech Instruments, Landsmeer, Netherlands). Briefly, 10 g of durian pulp was homogenised with 100 mL of distilled water for pH measurement. Following pH measurement, the sample solution was titrated against 0.1 N sodium hydroxide to pH 8.1, and the volume of sodium hydroxide needed was recorded.

Total soluble solids

The total soluble solids of each durian variety were determined according to Tagubase *et al*. (2016). Briefly, 4 g of pulp was homogenised with 12 mL of distilled water, and centrifuged at 12,000 *g* for 25 min at 4°C. The supernatant was then collected and dropped on the glass prism of a PAL-1 refractometer (Atago Co., Tokyo, Japan). The Brix (%) readings were recorded.

Firmness

The pulp firmness of each durian variety was determined using a TA-XT2 Texture Analyser (Stable Micro System, Godalming, UK) equipped with a P10 cylindrical probe according to Boonthanakorn *et al*. (2020). The seed of durian pulp was removed before being subjected to firmness measurement. During measurement, the probe was pressed to a depth of 5 mm at a test speed of 15 mm/min. Each pulp was pressed six times at different areas, and the average results were recorded in Newton (N).

Crude fat and crude protein contents

The crude fat and crude protein contents of each durian variety were determined using the Soxtec extraction method and micro Kjedahl method, respectively, following the AOAC (2005) method.

Volatile compound analysis

The extraction of volatile compounds each durian variety was carried out using the headspace solid-phase micro-extraction method as described by Tan *et al*. (2020) with slight modifications. First, 5 g of durian pulp was homogenised with 20% (w/w) NaCl in a 20 mL clear glass vial (Thermo Scientific, Loughborough, UK). Then, 1 µL of 4-methyl-1-pentanol was spiked into each vial as an internal standard, and the vial was sealed tightly with a screw-top cap and a PTFE/silicone septum. The fibre used was an SPME fibre syringe (DVB/CAR/PDMS 85 µm, Supelco, Inc., Pennsylvania, USA). The vial containing the sample was immersed in a water bath held at 40°C, and the SPME fibre was manually inserted into the headspace of each vial for 30 min before being injected into the gas chromatography-mass spectrometry (GC-MS).

The GC-MS analysis was carried out with the Agilent 6890N GC-MS system (Agilent Technologies Inc., Santa Clara, USA) using an HP-5MS capillary column (30 m × 0.25 mm ID × 0.25 µm film thickness; J&W Scientific, Folsom, USA). The oven temperature was set at 40°C for 3 min, increased to 60°C at 5°C/min, held for 2 min, increased to 90°C at 5°C/min, held for 2 min, increased to 150°C at 5°C/min, and held for 3 min. Lastly, the temperature was increased to 220°C at 10°C/min. Purified helium (purity 99.99%) was used as carrier gas at a flow rate of 0.7 mL/min at splitless mode. The detector temperature was maintained at 220°C. Scanning was operated at a mass-to-charge ratio of 30 - 500 *m/z* at 0.14 scan/s. Volatile compounds were identified based on the comparison of their mass spectra to the NIST library (NIST Standard Reference Database 1A V17, Agilent Technologies Inc.). Retention indices of the compounds were calculated using their retention times, and the retention times of the *n*-alkane series (C8-C20) were analysed under the same conditions.

Non-volatile compound analysis

Sugar content

The sugar content of each durian variety was determined according to Niponsak *et al*. (2015) with slight modification. First, durian pulp was homogenised with deionised water in a ratio of one to three, and centrifuged at 4°C for 20 min at 5,000 *g*. The supernatant was then collected and filtered through a 0.22 µm syringe filter. The analysis was performed using Waters 2695 Alliance HPLC (Thermo Fisher Scientific, Loughborough, UK) system equipped with an RI detector. The sugars were separated using Purospher Star NH_2 analytical column (5 µm packing size, 250 mm length, 4.6 mm ID; Merck, Darmstadt, Germany) at 35°C at a flow rate of 1.2 mL/min. The mobile phase used was 86:14 (v/v) acetonitrile and deionised water. The injection volume was 20 µL. External standards, such as glucose, sucrose, and fructose, were used to quantify the sugar contents.

Organic acid content

The organic acid content of each durian variety was determined according to Sturm *et al*. (2003) with slight modification. First, 3 g of durian pulp was homogenised with 9 mL of deionised water followed by centrifugation at 4°C for 20 min at 5,000 *g*. The collected supernatant was filtered through a syringe filter of 0.45 µm before injecting it into a high-performance liquid chromatography (Waters 2695 Alliance, Thermo Fisher Scientific, Loughborough, UK) system with a UV detector at 210 nm. A Purospher STAR RP18 analytical column (5 µm packing size, 250 mm length, 4.6 mm ID; Merck, Darmstadt, Germany) using 0.004 N aqueous sulphuric acid (H_2SO_4) as mobile phase at a flow rate of 0.6 mL/min was used to separate the organic acids. Organic acid standards used for quantification were acetic, lactic, tartaric, succinic, malic, and citric acids.

Total carotenoid content

The total carotenoid content of each durian variety was determined according to Tan *et al*. (2020). First, 15 g of durian pulp was homogenised with 25 mL of acetone. The homogenised mixture was then transferred into a separatory funnel containing 40 mL of petroleum ether. The acetone was removed by adding deionised water gradually into the separatory funnel, and removing the aqueous phase. This step was repeated until all the solvent was removed. Then, 15 g of anhydrous sodium sulphate was added to the extract, and the volume was made up to 50 mL with petroleum ether. Lastly, the extracts were examined using a spectrophotometer (Shimadzu Corporation, Kyoto, Japan). The absorbance of samples at 450 nm was recorded. The total carotenoid content (µg/g) of the durian pulp was calculated using Eq. 1:

$$\text{Total carotenoid content (µg/g)} = \frac{A \times V \times 104}{2592 \times W} \quad \text{(Eq. 1)}$$

where, A = absorbance, V = volume of extract (mL), 2592 = beta-carotene extinction coefficient in petroleum ether, and W = weight of sample (g).

Sensory evaluation

A total of 56 panellists (mean age = 23) were recruited from Universiti Putra Malaysia to evaluate the fresh durian samples using the hedonic test. All subjects gave their informed consent for inclusion before participating in the present work. The protocol of study was approved by the Ethics Committee for Research Involving Human Subjects Universiti Putra Malaysia (approval no.: JKEUPM-2022-1022). A nine-point scale (1-dislike extremely to 9-like extremely) was used to evaluate the likeness of consumers of each attribute based on surface colour (yellowness, orangeness), aroma (fermented, green, floral, fruity, sulphury), texture (moistness, smoothness, stickiness), taste (bitterness, creaminess, gassiness, sweetness), and overall aftertaste. The definition of each attribute is listed in Table 1. A whole pulp of each durian variety was served in a tightly closed plastic container. Between samples, mineral water and unsalted crackers were provided to panellists to clean their palates. Panellists were also instructed to take some fresh air before moving on to the next sample. Tokens of appreciation were given to all panellists upon completion of the sensory evaluation. The sensory evaluation was carried out in duplicates, and the mean scores of each attribute were recorded.

Table 1. Definition of sensory descriptors found in durian samples.

Sensory descriptor	Category	Definition
Yellow	C	Yellow colour of the durian pulp.
Orange	C	Orange colour of the durian pulp.
Fermented	A	Aroma associated with fermented odour.
Green	A	Aromatic characteristics of certain green fruits and underripe fruits in general.
Floral	A	Aroma associated with flowers.
Fruity	A	Aroma associated with a mixture of non-specific fruits: berries, apples/pears, tropical, melons; usually not citrus fruits.
Sulphury	A	Aroma associated with hydrogen sulphide and onions.
Moistness	T	Amount of moisture perceived as the sample is chewed.
Smoothness	T	Textural property manifested by an absence of detectable solid particles.
Stickiness	T	Degree of durian flesh adherence to hands.
Bitter	F	Basic taste on the tongue stimulated by solutions of caffeine, quinine, and certain other alkaloids.
Creamy	F	Smooth top note characteristic of fresh, sweet cream, or butter.
Gassiness	F	Gas-like feeling in the mouth.
Sweet	F	Basic taste on the tongue stimulated by sugars and high-potency sweeteners.
Overall aftertaste	F	Chemical feeling factor on the tongue or other skin surfaces of the oral cavity described as puckering/dry, and associated with tannins or alum.

C = surface colour, A = aroma, T = texture, F = taste/flavour.

Statistical analysis

The data were presented as mean ± standard deviation (SD), and compared by One-way analysis of variance (ANOVA). Differences among mean values were tested for significance ($p < 0.05$) using Tukey's multiple comparison tests. Minitab Statistical Software version 19 (Minitab Inc., Pennsylvania, USA) was used to perform ANOVA and Tukey's multiple *t*-tests. Principal component analysis (PCA) and Pearson's correlation analysis ($p = 0.05$) were carried out using XLSTAT (Addinsoft, Paris, France) on physicochemical properties, volatile and non-volatile compounds, and sensory attributes of each durian variety.

Results and discussion

Physicochemical properties

The results of the physicochemical properties of all durian varieties studied are listed in Table 2. There were significant differences ($p < 0.05$) observed in physicochemical properties across all durian varieties. The results reported the highest L^* (lightness) in Johor "D24". However, Johor "D24" scored the lowest a^* and b^* (yellowness) values compared to "D197" and "D200". "D200" significantly scored the highest a^* value compared with others. Pahang "D197" scored the highest b^* values, due to its golden yellow pulp. The L^*, a^* and b^* values measured were consistent with the colour of each durian pulp, where "D24" had light yellow pulp, "D197" had golden yellow pulp, and "D200" had orange-yellow pulp. The intensity of the red and yellow colours can be related to the concentration of phytochemicals such as carotenoids in durian (Wisutiamonkul *et al*., 2015).

pH will affect the quality of fruits. Fruits with higher pH will usually score higher on sweetness in sensory tests (Savic *et al*., 2024). In the present work, the pH of durians determined was neutral, between 7.25 and 7.58, and this corresponded to the pH values previously reported by Voon *et al*. (2007a), in which the pH for "D24" durian was between 6.88 and 7.60. The neutral pH of durians can be explained by the buffering capacity of the durian pulp tissue (Voon *et al*., 2007a). Meanwhile, the titratable acidity (TA) of durian samples was in the range of 40.23 to 74.49 × 10^{-3} g/kg. From the results, Pahang "D197" and "D24" had higher TA compared to similar variety from Johor, whereas Penang "D200" had higher TA than Pahang "D200".

The soluble solid content of durian samples varied from 18.7 to 24.7%. Similar results were reported by Belgis *et al*. (2016), in which, TSS values were between 12.5 and 23.0% for durian from Indonesia. According to Onsawai *et al*. (2021), the decrease in TSS is due to the increase in the water content in durian pulp. The increase in TSS could also be caused by the production of enzymes such as polygalacturonase, pectinesterase, beta-galactosidase, and cellulase, as well as increased starch breakdown during fruit ripening (Khurnpoon *et al*., 2008; Maninang *et al*., 2011).

For firmness, the results found that the values were in the range of 0.33 to 0.48 N. Johor "D24" had the highest firmness whereas Pahang "D197" had the lowest. It was also observed that Pahang durians had lower firmness than durians of the same varieties from Johor and Penang. The variation in firmness of durian pulp might be linked to the strength of the flesh inside, and the activity of polygalacturonase enzyme in the pulp during fruit ripening (Imsabai *et al*., 2002; Onsawai *et al*., 2021).

Meanwhile, the fat content of the durians ranged from 7.33 to 13.48%, in which the highest values were observed in Pahang and Penang "D200". Fat content in foods usually suggests that it could have higher creaminess, as well as contribute to flavour of food (Upadhyay *et al*., 2020). A study by Onsawai *et al*. (2021) also found that the amount of fats and sticky mouthfeel perceived while consuming durian were positively correlated.

Table 2 also shows that the protein content of durian samples ranged between 3.58 and 4.49%. The protein contents in Pahang durians were higher than in Johor and Penang durians, whereas differences were not observed among varieties. According to Eskin and Hoehn (2013), proteins are one of the precursors to synthesise volatiles. During fruit ripening, amino acids are converted to branched-chain alcohols, esters, and acids which contribute to the aroma of fruits.

Volatile compounds

Table 3 shows the volatile composition in the headspace of three durian varieties identified using GC-MS. A total of 18 volatile compounds, including five sulphur-containing compounds, five esters, four alcohols, one ketone, and three other compounds were identified. The results were in agreement with previous studies that these volatile groups are the major groups that have been reported in Malaysian durians (Voon *et al*., 2007b; Tan *et al*., 2020).

Sulphur-containing compounds are associated with the strong and pungent onion-like aroma in durian (Weenen *et al*., 1996). The five sulphur compounds found in durian samples were diethyl disulphide, ethyl isopropyl disulphide, 3,5-dimethyl-1,2,4-trithiolane, diethyl trisulphide, and 1,1-bis(ethylthio)-ethane. Diethyl disulphide was present in all durian samples studied as the major sulphur compound, followed by diethyl trisulphide, which was similar to the results of Näf and Velluz (1996). Diethyl disulphide was highest in Johor "D197", followed by Penang "D200" and Pahang "D200".

Table 2. Physicochemical qualities and non-volatiles of three durian varieties from different geographical regions in Malaysia.

Analysis (unit)	Sample						Significance
	Pahang "D197"	Johor "D197"	Pahang "D24"	Johor "D24"	Pahang "D200"	Penang "D200"	
Physicochemical							
L*	77.44 ± 5.18^{bcd}	79.65 ± 1.50^{abc}	81.23 ± 2.95^{ab}	82.71 ± 2.18^{a}	75.22 ± 3.00^{d}	77.05 ± 3.67^{cd}	≤ 0.000
a*	4.35 ± 1.16^{c}	4.40 ± 1.32^{c}	2.02 ± 0.70^{cd}	1.97 ± 1.42^{d}	16.28 ± 3.96^{a}	13.03 ± 2.36^{b}	≤ 0.000
b*	56.79 ± 4.68^{a}	55.88 ± 4.98^{a}	37.72 ± 4.07^{b}	37.97 ± 5.12^{b}	53.79 ± 6.42^{a}	55.39 ± 3.76^{a}	≤ 0.000
pH	7.26 ± 0.21^{b}	7.30 ± 0.14^{b}	7.38 ± 0.06^{ab}	7.58 ± 0.10^{a}	7.25 ± 0.19^{b}	7.32 ± 0.24^{b}	≤ 0.000
TA (10^{-3} g/kg)	70.02 ± 25.42^{a}	55.87 ± 16.74^{ab}	74.49± 11.83^{a}	40.23 ± 11.27^{b}	46.19 ± 13.97^{b}	70.77 ± 28.65^{a}	≤ 0.000
TSS (%)	21.0 ± 2.4^{abc}	23.4 ± 2.4^{ab}	20.1 ± 2.0^{bc}	18.7 ± 2.9^{c}	24.7 ± 2.1^{a}	20.9 ± 2.8^{abc}	0.057
Firmness (N)	0.33 ± 0.08^{c}	0.38 ± 0.07^{bc}	0.34 ± 0.04^{bc}	0.48 ± 0.16^{a}	0.39 ± 0.08^{ab}	0.42 ± 0.10^{bc}	≤ 0.000
Fat content (%)	8.44 ± 0.55^{cd}	7.33 ± 1.16^{d}	11.99 ± 1.22^{ab}	10.55 ± 1.47^{bc}	11.54 ± 1.75^{ab}	13.48 ± 0.74^{a}	≤ 0.000
Protein content (%)	3.83 ± 0.32^{ab}	3.58 ± 0.22^{b}	4.49 ± 0.37^{a}	3.99 ± 0.30^{ab}	4.30 ± 0.63^{ab}	3.69 ± 0.82^{ab}	0.022
Sugar							
Fructose (g/kg)	11.45 ± 0.16^{a}	11.57 ± 0.08^{a}	7.74 ± 0.11^{d}	8.69 ± 0.02^{b}	8.43 ± 0.09^{b}	8.07 ± 0.10^{c}	≤ 0.000
Glucose (g/kg)	8.93 ± 0.21^{b}	10.64 ± 0.19^{a}	4.60 ± 0.09^{e}	8.10 ± 0.19^{c}	8.11 ± 0.08^{c}	6.70 ± 0.42^{d}	≤ 0.000
Sucrose (g/kg)	33.44 ± 0.15^{d}	24.17 ± 0.03^{e}	36.00 ± 0.23^{c}	33.56 ± 0.07^{d}	52.64 ± 0.30^{a}	49.35 ± 0.17^{b}	≤ 0.000
Organic acid							
Acetic acid (g/kg)	1.31 ± 0.15^{bc}	0.69 ± 0.21^{c}	1.34 ± 0.41^{b}	1.91 ± 0.35^{a}	1.51 ± 0.15^{ab}	1.47 ± 0.31^{ab}	≤ 0.000
Citric acid (g/kg)	5.72 ± 0.53^{ab}	3.47 ± 1.20^{ab}	5.17 ± 2.12^{a}	5.33 ± 1.27^{a}	4.84 ± 1.80^{ab}	2.37 ± 0.95^{b}	0.019
Lactic acid (g/kg)	0.37 ± 0.10^{b}	0.62 ± 0.44^{b}	1.66 ± 0.69^{a}	ND	ND	ND	0.018
Malic acid (g/kg)	1.24 ± 0.39^{b}	0.32 ± 0.04^{d}	0.61 ± 0.16^{cd}	1.73 ± 0.21^{a}	1.27 ± 0.13^{ab}	1.05 ± 0.41^{bc}	≤ 0.000
Succinic acid (g/kg)	3.46 ± 0.79^{bc}	6.09 ± 1.21^{a}	5.53 ± 1.26^{a}	4.82 ± 0.23^{ab}	1.14 ± 0.24^{d}	2.43 ± 0.54^{cd}	≤ 0.000
Tartaric acid (g/kg)	1.84 ± 0.46^{a}	0.74 ± 0.06^{cd}	1.18 ± 0.14^{bc}	1.55 ± 0.12^{ab}	0.54 ± 0.02^{d}	1.53 ± 0.42^{ab}	≤ 0.000
Carotenoid							
Total carotenoid (10^{-3} g/kg)	1.01 ± 0.18^{bc}	0.97 ± 0.19^{c}	0.65 ± 0.12^{c}	0.76 ± 0.18^{c}	1.41 ± 0.25^{ab}	1.54 ± 0.18^{a}	≤ 0.000

Values are mean ± SD from three replicates (n = 3) for sugars, six replicates (n = 6) for physicochemical and organic acids, and four replicates (n = 4) for total carotenoid. Means followed by different lowercase superscripts within similar row are significantly (p < 0.05) different.

Table 3. Volatile compounds of three durian varieties from different geographical regions in Malaysia.

Peak	RT	Compound	Calculated RI	Reported LRI [a]	Peak area (%)					
					Pahang "D197"	Johor "D197"	Pahang "D24"	Johor "D24"	Pahang "D200"	Penang "D200"
				Alcohol						
1	3.74	3-Methylbutan-1-ol	668	700	ND	1.05	0.59	ND	0.30	0.77
2	7.34	1-Hexanol	875	876	0.23	ND	0.46	0.52	0.47	0.45
3	8.40	2-Isobutyl-2-propen-1-ol	915	902	ND	ND	0.17	ND	0.18	0.20
5	9.14	2,4-Hexadien-1-ol	933	916	ND	ND	0.31	ND	ND	ND
				Subtotal	0.23	1.05	1.53	0.52	0.95	1.42
				Ester						
6	9.50	Ethyl 3-hydroxybutyrate	942	943	ND	0.15	ND	ND	ND	ND
7	9.87	Propyl 2-methylbutanoate	951	954	ND	ND	ND	0.48	ND	ND
8	11.24	Hexyl acetate	984	983	ND	0.68	0.17	0.39	0.29	0.29
11	14.72	Sorbyl acetate	1075	1090	ND	ND	0.48	ND	ND	ND
15	19.76	Ethyl octanoate	1199	1199	ND	ND	ND	0.44	ND	0.14
				Subtotal		0.83	0.65	1.31	0.29	0.43
				Ketone						
16	19.87	2,8-Dimethyl-5-nonanone	1203	*	0.23	ND	0.31	ND	0.25	ND
				Sulphur compound						
4	8.74	Diethyl disulphide	923	922	1.01	4.81	0.77	0.68	1.91	2.41
9	12.52	Ethyl isopropyl disulphide	1016	985	ND	ND	0.28	ND	0.38	0.32
12	16.89	3,5-dimethyl-1,2,4-trithiolane	1130	1130	ND	ND	0.16	ND	ND	ND
13	17.23	Diethyl trisulphide	1138	1140	ND	ND	0.41	0.52	0.32	0.65
18	23.79	Ethyl isopropyl sulphide	1319	*	ND	ND	0.17	ND	ND	ND
				Subtotal	1.01	4.81	1.79	1.20	2.61	3.38
				Other						
10	13.36	2-Propyl-tetrahydrofuran	1039	*	1.45	1.12	1.24	1.03	1.44	1.23
14	19.45	1-Chloro-2-ethenyl-1-methylcyclopropane	1192	*	0.45	ND	0.71	ND	ND	ND
17	20.58	1-Bromocyclohexene	1223	*	0.38	0.24	0.50	0.36	0.38	0.39
				Subtotal	2.28	1.36	2.45	1.39	1.82	1.62

Values are mean ± SD from three replicates (n = 3). ([a]): Kovats indices for HP5-MS column from NIST and Pherobase databases. (*): unidentified. ND: not detected.

According to Chin *et al*. (2007), disulphides and trisulphides were transformed from ethanethiol and propanethiol, which are more unstable to a more stable form. Moreover, 3,5-dimethyl-1,2,4-trithiolane was only detected in Pahang “D24”. However, in the study of Tan *et al*. (2020), it was present in nearly equal amounts in all three varieties (“D197”, “D24”, and “D200”). Among all samples, “D200” had the highest number of sulphur compounds. This could lead to a stronger sulphury aroma in the “D200” samples.

As for ester compounds, the esters identified in durian samples were ethyl 3-hydroxybutyrate, propyl 2-methylbutanoate, hexyl acetate, sorbyl acetate, and ethyl octanoate. Esters are responsible for the fruity aroma of durian samples. According to Tan *et al*. (2020), esters comprised 87, 48, and 36% in “D197”, “D24”, and “D200”, respectively. However, in the present work, no ester was found in Pahang “D197”, whereas for other samples, the ester detected was in a low amount. The two major esters presented in “D197”, “D24”, and “D200” in the previous study were 2-methyl butanoate and propyl 2-methyl butanoate (Tan *et al*., 2020). Nevertheless, 2-methyl butanoate was not detected in the present work while propyl 2-methyl butanoate was only detected in Johor “D24”. On the other hand, alcohols and ketones were also detected in the durian samples. Except for 2-isobutyl-2-propen-1-ol, the other three alcohols, which were 3-methylbutan-1-ol, 1-hexanol, and 2,4-hexadien-1-ol, have been previously reported in Malaysian durians. 2,8-Dimethyl-5-nonanone was first detected in durians, and it was only detected in three Pahang durians, which could have been due to differences in environmental factors or agricultural practices in different geographical regions (Mattheis and Fellman, 1999).

Non-volatile compounds

Sugar, organic acid, and total carotenoid contents in each durian sample were evaluated, and a significant difference (p < 0.05) was observed between the samples as shown in Table 2. The sweetness of fruit is a key factor in its overall quality, and largely determined by its sugar composition. Results showed that sucrose was the highest sugar in all samples, followed by fructose and glucose. Similar results were reported by Wasnin *et al*. (2012). However, Voon *et al*. (2007a) reported that the main sugars found in durian were sucrose, followed by glucose and fructose. In the present work, the sugar contents of durian ranged from 24.17 to 52.64 g/kg for sucrose, 7.74 to 11.57 g/kg for fructose, and 4.60 to 10.64 g/kg for glucose. Based on the study of Selvaraj and Pal (1984) on enzyme activities of two sapodilla cultivars during development and ripening, the ratio of sugars in different fruit varieties could be different, due to enzyme activities.

Six organic acids, which were tartaric, malic, lactic, acetic, succinic, and citric acids were determined. The results were in accordance with the study of Tan *et al*. (2020) on seven durian varieties from Malaysia including “D197”, “D24”, “D88”, “D101”, “XO”, “D175”, and “D200”. Four organic acids, namely citric, tartaric, succinic, and malic acids have also been detected in five Malaysian durian varieties - “D2”, “D24”, “D101”, “MDUR78”, and “Chuk” (Voon *et al*., 2007a). Citric and succinic acids have been reported in Thai durians (Tagubase *et al*., 2016). Lactic acid was detected in low amounts in only three samples, which were Pahang “D197”, Johor “D197”, and Pahang “D24”. The presence of organic acids could contribute to the sourness of the durian taste. However, as durians normally contain only low organic acid content, the sourness of acids is masked by the sweetness from sugars, due to high sugar composition (Lawless and Heymann, 2010; Sangpong *et al*., 2021).

Carotenoids were found to affect the yellow intensity of durian pulp. The total carotenoid content of durian varieties found in the present work varied from 0.65 to 1.54 × 10^{-3} g/kg, the highest was in Penang “D200”, followed by Pahang “D200” and “D197”. The total carotenoid contents agreed with those investigated by Belgis *et al*. (2016), which were between 12.5 and 23.0%. The study of Unlu *et al*. (2005) on the effect of the addition of avocado oil or fruit on carotenoid availability showed that fat content played a key role in carotenoid bioavailability. Therefore, the variation in total carotenoid contents in durian varieties could have been due to the fat content. In addition, durians with darker yellow pulp were found to have higher carotenoid contents (Wisutiamonkul *et al*., 2015). This agreed with our findings, where, in contrast to “D24”, “D197”, and “D200”, with higher total carotenoid contents recorded higher a^* and b^* values, resulting in a darker yellow colour.

Sensory evaluation

Figure 1 shows the likeness scores obtained for each characteristic of durian from 56 untrained panellists using the hedonic test. The sensory preferences of durians were assessed for surface colour (yellowness, orangeness), aroma (fermented, green, floral, fruity, sulphury), texture (moistness, smoothness, stickiness), taste (bitterness, creaminess, gassiness, sweetness), and overall aftertaste. There were significant differences ($p < 0.05$) in the yellowness and orangeness among the durian of different varieties. "D197" with golden yellow flesh had the highest score for yellowness, whereas "D200" with orangey-yellow scored the highest for orangeness. "D24" had the lowest scores in colour due to its light-yellow flesh, which was less attractive compared to "D197" and "D200". However, in terms of geographical region, the colour of each variety was not significantly different ($p > 0.05$).

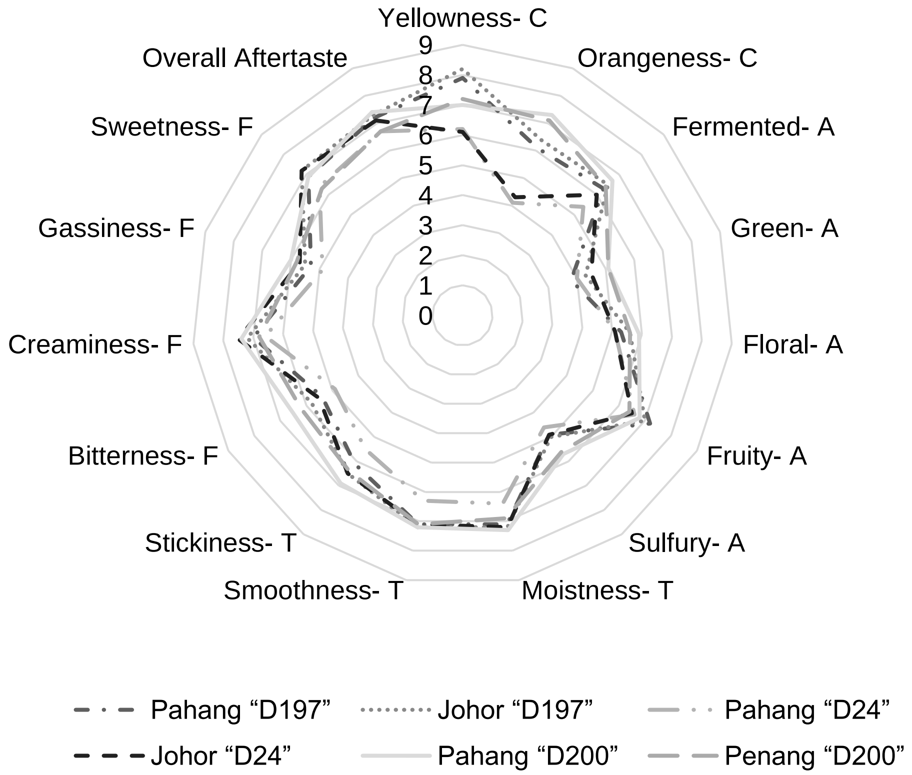

Figure 1. Sensory preference scores of 15 sensory attributes using the hedonic test of three durian varieties from different geographical regions in Malaysia. Values are mean of two replicates ($n = 2$).

Aroma (fermented, green, floral, fruity, sulphury) and texture (moistness, smoothness, stickiness) did not show any significant differences ($p > 0.05$) across all durian varieties. According to Mohd Ali *et al*. (2020), the aroma of durian is characterised by two different notes: one is strong and onion-like, and the other is delicate and fruity. The sulphury aroma of durian was reported to be attributed to the presence of sulphur-containing compounds such as disulphides, thiols, and trisulphides, whereas esters such as ethyl propanoate, propyl propanoate, and ethyl 2-methylbutanoate are responsible for the fruity aroma (Weenen *et al*., 1996; Chin *et al*., 2008). According to Voon *et al*. (2007b), the fruity aroma could also be associated with the aldehydes found in durians. The aroma scores obtained for Johor durians were higher than those from Pahang. Meanwhile, the green aroma which reflects the fresh aroma of durian was reported by Voon *et al*. (2007b) to correspond to 1-hexanol and benzyl alcohol.

In terms of texture, Pahang "D200" scored the highest by panellists for moistness, smoothness, and stickiness, which could have been due to its flesh which was not fibrous, and contributed to its melt-in-mouth texture compared to the others. In addition, the fat content in Pahang "D200" was also higher compared to the others (Table 2). There was also no significant difference ($p > 0.05$) found in the taste of the durians across all varieties. However, the bitterness of "D200" scored the highest by panellists. Furthermore, the sweet taste likeness of the durian varieties rated by panellists from lowest to highest was Penang "D200", Pahang "D24", Pahang "D200", Pahang "D197", Johor "D197", and Johor "D24".

The low likeness scores obtained for "D200" could have been due to the intense bitter taste which masked the sweet taste in them. Overall, Pahang "D200" obtained the highest scores in the sensory evaluation. This could have been possibly due to its attractive appearance, the best texture, and a stronger aroma compared to the others. Pahang "D24" had the lowest likeness scores among all durian samples.

Correlation between physicochemical properties, volatile and non-volatile compounds, and sensory preference

Correlation analysis was carried out to study the relationship between the physicochemical properties, volatile and non-volatile compounds, and sensory preference of the durians at $p < 0.05$ as shown in Tables 4a, 4b, and 4c, respectively. A positive correlation was observed between orangeness and a^* ($r = 0.842$) and b^* ($r = 0.911$). In addition, carotenoid was also highly correlated with orangeness ($r = 0.919$). This implied that samples with high a^*, b^*, and carotenoid content had high orangeness. Besides that, the sweetness of durian showed a high correlation with glucose content ($r = 0.814$). TSS did not show a strong correlation with sweetness. Hence, TSS might not be a reliable indicator for sweetness in durian samples. This agreed with Voon *et al*. (2007a) and Tan *et al*. (2020), whereby TSS did not show a strong correlation with the sweetness and sugar content in durian samples.

In the study of Lee *et al.* (2013), fructose, glucose, and sucrose were the predominant sugars found in all the tropical fruits studied. Among them, sucrose was the predominant sugar in cempedak, mangosteen, and rambutan, whereas fructose and glucose were the main sugars in custard apple, chiku, and starfruit. The ratio of sugar to acid is a key indicator of ripeness for many fruits. For instance, the maturation index of the Portuguese apple was determined using the total sugar-to-acid content ratio (Guiné *et al.*, 2009). The balance between sugar and acid also plays a key role in how sweetness is perceived. For instance, durian with high sugar content is often perceived as sweeter compared to other tropical fruits such as pineapples or tamarinds with higher acid levels, which may taste less sweet due to the sourness that balances out the sweetness. Hence, it can be concluded that the overall sweetness perception of fruit could be affected by the concentration of organic acids although it contains high sugars, which adds complexity to the flavour profile.

For volatile compounds, it was observed that 1-hexanol was negatively correlated ($r = -0.741$) with fruity aroma. This could be explained by the fact that 1-hexanol produces a sweet and alcoholic aroma, which could mask the fruity aroma in the samples when its concentration was high, which led to a decrease in panellists' likeness. Meanwhile, a strong negative correlation was found between 2,4-hexadien-1-ol with fermented ($r = -0.866$) and gassiness ($r = -0.789$) of durians. Ethyl isopropyl disulphide and diethyl trisulphide were positively correlated with green aroma, with *r* values

Table 4a. Pearson correlation coefficients between physicochemical and sensory of durian.

Variable	*L**	*a**	*b**	Firmness	pH	TA	TSS	Fat	Protein
Yellowness-C	-0.503	0.161	0.895	-0.466	-0.716	0.737	0.511	-0.642	-0.715
Orangeness-C	-0.907	0.842	0.911	-0.119	-0.759	0.651	0.591	0.018	-0.437
Fermented-A	-0.731	0.694	0.836	0.118	-0.528	0.528	0.618	-0.235	-0.542
Green-A	-0.470	0.842	0.225	0.570	-0.061	0.054	0.186	0.597	-0.056
Floral-A	-0.832	0.878	0.740	-0.049	-0.685	0.322	0.765	0.058	-0.211
Fruity-A	-0.302	-0.158	0.545	-0.665	-0.579	0.324	0.571	-0.831	-0.234
Sulphury-A	-0.790	0.968	0.583	0.280	-0.422	0.362	0.391	0.416	-0.184
Moistness-T	-0.332	0.334	0.492	0.382	-0.088	0.219	0.463	-0.450	-0.468
Smoothness-T	-0.332	0.334	0.492	0.382	-0.088	0.219	0.463	-0.450	-0.468
Stickiness-T	-0.456	0.632	0.464	0.520	-0.113	0.141	0.491	-0.089	-0.350
Bitterness-F	-0.736	0.905	0.626	0.318	-0.403	0.327	0.512	0.213	-0.289
Creaminess-F	0.006	0.137	0.045	0.581	0.280	-0.235	0.340	-0.352	-0.152
Gassiness-F	-0.494	0.746	0.400	0.622	-0.052	0.187	0.296	0.206	-0.291
Sweetness-F	0.240	-0.289	0.048	0.270	0.237	-0.197	0.348	-0.773	-0.288
Overall aftertaste	-0.306	0.172	0.411	-0.021	-0.267	-0.024	0.747	-0.666	-0.163

Table 4b. Pearson correlation coefficients between volatiles and sensory of durian.

Variable	3-Methylbutan-1-ol	1-Hexanol	2-Isobutyl-2-propen-1-ol	Diethyl disulphide	2,4-Hexadien-1-ol	Ethyl 3-hydroxybutyrate	Propyl 2-methylbutanoate	Hexyl acetate	Ethyl isopropyl disulphide
Yellowness-C	0.367	**-0.872**	-0.349	**0.710**	-0.514	0.628	-0.571	0.210	-0.331
Orangeness-C	0.290	-0.275	0.281	0.546	-0.634	0.184	-0.563	0.124	0.342
Fermented-A	0.103	-0.343	-0.065	0.562	**-0.866**	0.300	-0.230	0.309	0.033
Green-A	0.077	0.673	0.770	-0.067	-0.149	-0.418	0.030	0.056	**0.799**
Floral-A	0.361	-0.196	0.375	0.588	-0.510	0.255	-0.510	0.302	0.472
Fruity-A	-0.122	**-0.741**	-0.556	0.258	-0.238	0.397	-0.397	-0.114	-0.482
Sulphury-A	0.129	0.209	0.518	0.280	-0.581	-0.131	-0.244	0.116	0.585
Moistness-T	-0.249	-0.266	-0.462	0.338	**-0.912**	0.271	0.271	0.370	-0.340
Smoothness-T	-0.249	-0.266	-0.462	0.338	**-0.912**	0.271	0.271	0.370	-0.340
Stickiness-T	-0.050	-0.039	-0.072	0.396	**-0.842**	0.189	0.189	0.463	0.046
Bitterness-F	0.173	0.042	0.339	0.434	-0.693	0.071	-0.184	0.305	0.426
Creaminess-F	-0.384	-0.010	-0.465	0.113	-0.679	0.164	0.585	0.426	-0.333
Gassiness-F	-0.076	0.205	0.150	0.248	**-0.789**	-0.042	0.208	0.329	0.239
Sweetness-F	-0.262	-0.428	**-0.816**	0.258	-0.528	0.485	0.485	0.485	**-0.712**
Overall aftertaste	-0.239	-0.426	-0.498	0.318	-0.597	0.380	0.054	0.291	-0.341

Variable	2-Propyl-tetrahydrofuran	Sorbyl acetate	3,5-dimethyl-1,2,4-trithiolane	Diethyl trisulphide	1-Chloro-2-ethenyl-1-methylcyclopropane	Ethyl octanoate	2,8-Dimethyl-5-nonanone	1-Bromocyclohexene	Ethyl isopropyl sulphide
Yellowness-C	0.311	-0.514	-0.514	**-0.742**	0.057	-0.560	-0.191	-0.678	-0.514
Orangeness-C	0.506	-0.634	-0.634	-0.168	0.433	-0.431	-0.147	-0.425	-0.634
Fermented-A	0.318	**-0.866**	**-0.866**	-0.279	0.194	-0.170	-0.334	-0.686	**-0.866**
Green-A	0.064	-0.149	-0.149	**0.766**	0.568	0.213	-0.116	0.225	-0.149
Floral-A	0.421	-0.510	-0.510	-0.121	0.255	-0.434	-0.074	-0.414	-0.510
Fruity-A	0.503	-0.238	-0.238	**-0.972**	-0.556	-0.582	0.308	-0.403	-0.238
Sulphury-A	0.343	-0.581	-0.581	0.301	0.544	-0.072	-0.201	-0.202	-0.581
Moistness-T	0.053	**-0.912**	**-0.912**	-0.320	-0.173	0.219	-0.417	**-0.761**	**-0.912**
Smoothness-T	0.053	**-0.912**	**-0.912**	-0.320	-0.173	0.219	-0.417	**-0.761**	**-0.912**
Stickiness-T	0.025	**-0.842**	**-0.842**	0.002	0.086	0.219	-0.451	-0.643	**-0.842**
Bitterness-F	0.248	-0.693	-0.693	0.151	0.410	-0.054	-0.307	-0.420	-0.693
Creaminess-F	-0.180	-0.679	-0.679	-0.137	-0.398	0.465	-0.351	-0.591	-0.679
Gassiness-F	0.032	**-0.789**	**-0.789**	0.283	0.332	0.317	-0.462	-0.442	**-0.789**
Sweetness-F	-0.268	-0.528	-0.528	-0.539	-0.654	0.281	-0.314	**-0.727**	-0.528
Overall aftertaste	0.250	-0.597	-0.597	-0.654	-0.597	-0.137	0.002	-0.649	-0.597

Absolute linear correlation coefficients > |0.7| are in bold fonts.

Table 4c. Pearson correlation coefficients between non-volatiles and sensory of durian.

Variable	Sucrose	Fructose	Glucose	Tartaric acid	Malic acid	Lactic acid	Acetic acid	Citric acid	Succinic acid	Carotenoid
Yellowness-C	-0.281	0.838	0.736	-0.103	-0.441	-0.188	-0.775	-0.331	-0.026	0.362
Orangeness-C	0.499	0.224	0.429	-0.328	-0.088	-0.573	-0.313	-0.549	-0.686	0.919
Fermented-A	0.300	0.398	0.718	-0.334	0.110	-0.767	-0.227	-0.383	-0.578	0.771
Green-A	0.768	-0.516	-0.039	-0.387	0.265	-0.632	0.311	-0.585	-0.666	0.783
Floral-A	0.532	0.074	0.381	-0.645	-0.152	-0.480	-0.306	-0.498	-0.640	0.837
Fruity-A	-0.443	0.869	0.641	-0.076	-0.245	0.069	-0.586	0.376	0.085	-0.106
Sulphury-A	0.795	-0.238	0.149	-0.339	0.233	-0.714	0.138	-0.534	-0.846	0.956
Moistness-T	0.018	0.472	0.844	-0.212	0.405	-0.819	0.019	-0.001	-0.342	0.377
Smoothness-T	0.018	0.472	0.844	-0.212	0.405	-0.819	0.019	-0.001	-0.342	0.377
Stickiness-T	0.343	0.124	0.624	-0.413	0.364	-0.857	0.104	-0.270	-0.528	0.618
Bitterness-F	0.639	-0.072	0.362	-0.447	0.183	-0.757	0.022	-0.526	-0.739	0.898
Creaminess-F	-0.037	0.220	0.650	-0.285	0.524	-0.672	0.258	0.227	-0.171	0.066
Gassiness-F	0.563	-0.124	0.391	-0.282	0.479	-0.907	0.302	-0.373	-0.673	0.742
Sweetness-F	-0.538	0.609	0.814	-0.208	0.197	-0.339	-0.116	0.351	0.272	-0.296
Overall aftertaste	-0.156	0.590	0.812	-0.449	0.144	-0.426	-0.219	0.308	-0.172	0.102

of 0.799 and 0.766, respectively. This was likely due to the strong sulphury aroma produced by the sulphur compounds which reduced the perception of unfavoured green aroma during sensory evaluation. At the same time, diethyl trisulphide was found to have a negative correlation (r = -0.972) with fruity aroma, where a higher concentration of diethyl trisulphide was associated with a lower likeness score of fruity smell.

Furthermore, lactic acid was found to have a strong negative correlation with the texture of durians, which were moistness (r = -0.819), smoothness (r = -0.819), and stickiness (r = -0.857). Hence, this implied that a higher presence of lactic acid might reduce the moistness, smoothness, and stickiness of durians. In the study of Tan *et al*. (2020), succinic acid was negatively correlated with stickiness. However, in the present work, only a moderate negative correlation (r = -0.528) was shown between succinic acid and stickiness. On the contrary, durian with higher glucose content was found to have higher moistness and smoothness as they showed a positive correlation (r = 0.844). Meanwhile, the sulphury aroma in durian had a negative correlation with both lactic acid (r = -0.714) and succinic acid (r = -0.846). In addition, a negative correlation was also shown between bitterness with lactic acid (r = -0.757) and succinic acid (r = -0.739).

PCA of physicochemical properties, volatile and non-volatile compounds, and sensory evaluation

Principal component analysis was used to determine the important factors of variation of data among three durian varieties, and to show the cluster patterns. The results showed that the first two principal components accounted for 64.30% of the total variance, 39.00% from PC1, and 25.30% from PC2, respectively (Figure 2). Based on the PCA plot, the six durian samples were clearly separated into three clusters. Pahang "D200" and Penang "D200", as well as Pahang and Johor "D197", were separated across the PC1 axis, whereas PC2 separated Penang "D200", Pahang "D200", and Pahang "D24" from Pahang and Johor "D197" and Johor "D24".

As expected, the separation of clusters was based on varieties. This indicated that while environmental and agronomic factors may have a significant impact on cultivar characteristics, genetic influences are still more significant (Belgis *et al*., 2016). The factors that contributed to the variation are shown in the loading plots (Figures 3a and 3b). Fermented aroma, 2,4-hexadien-1-ol, ethyl isopropyl sulphide, sorbyl acetate, as well as 3,5-dimethyl-1,2,4-trithiolane, rendered the variance of PC1 (Figure 3a). Meanwhile, the factors that contributed to the variation of PC2 were sucrose, green aroma, 1-hexanol, and diethyl trisulphide (Figure 3b). "D200" was distinguished from the others due to its high a^* hue and carotenoid, whereas "D197" was associated with 3-hydroxybutyrate, fruity aroma, and fructose. The factors associated with Pahang "D24" included 3,5-dimethyl-1,2,4-trithiolane and ethyl isopropyl sulphide. Johor "D24" was characterised by a high L^* hue and succinic acid.

Conclusion

The present work demonstrated the physicochemical properties, volatile compounds, non-volatile compounds, and sensory preferences of three popular premium durian varieties in Malaysia. The physicochemical properties and non-volatiles were significantly (p < 0.05) different among the three popular premium durian varieties in

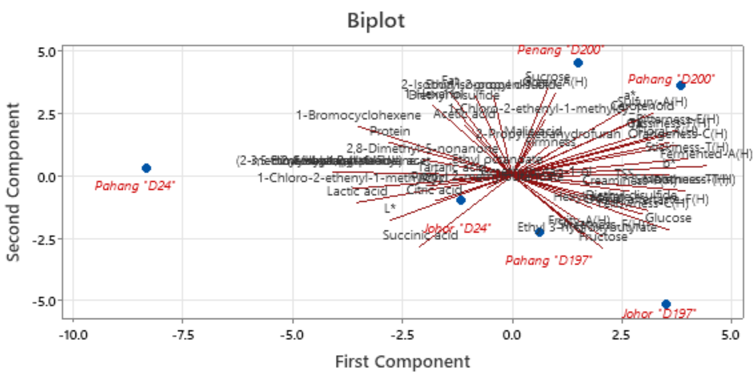

Figure 2. Principal component analysis (PCA) score plot of three durian varieties from different geographical regions in Malaysia.

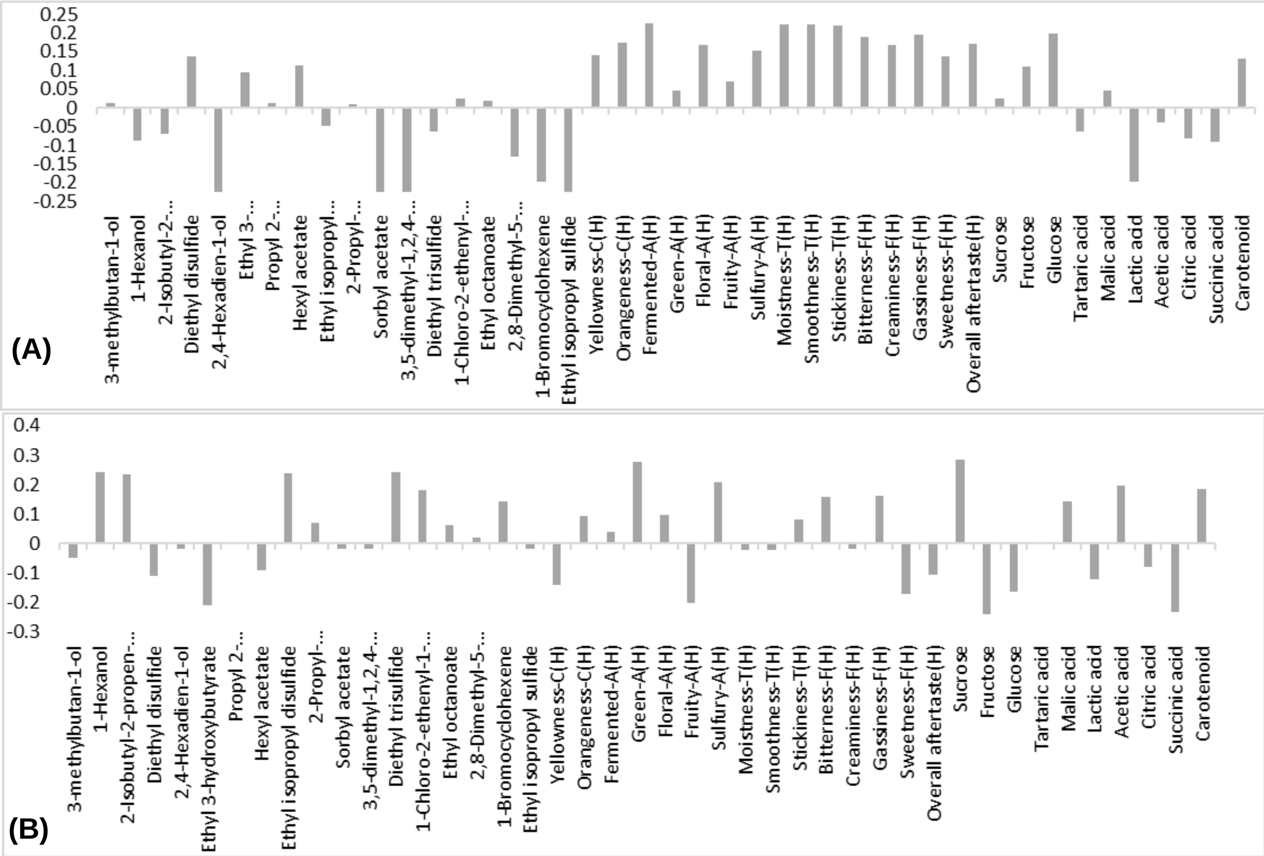

Figure 3. Factor loading plot of PC1 (A) and PC2 (B) of three durian varieties from different geographical regions in Malaysia.

Malaysia. In terms of geographical region, the differences were less significant in all three varieties. Pahang "D200" showed the highest *a**, with the second highest carotenoid content, presenting a more appealing orangey-yellow colour, followed by Pahang "D197" with the highest *b**, giving a golden yellow pulp. Johor "D24" had the highest *L** and firmness. On the other hand, sugar (sucrose, fructose, and glucose) and organic acid (tartaric and malic acids) contents in durians had a significant difference across the varieties, and when durians were planted in different geographical regions. Eighteen volatile compounds found in samples explained the difference in aroma and taste of each durian variety. A positive correlation was found between sucrose and sweetness, implying that sucrose contributed to the major sweetness in durian. Among all varieties, Pahang "D200" scored the highest preference from panellists due to its attractive pulp colour, best texture, and stronger aroma compared to the others. In conclusion, our findings will allow consumers to compare the sensory qualities of these durian varieties, and aid in developing molecular markers for durian varieties that could potentially be beneficial in the future. Further research focusing on flavour compounds should be conducted to investigate differences in flavour profiles and genetic variations of durians.

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