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Chemical profile and antimicrobial activity of essential oil and methanol extract from peels of four *Durio zibethinus* L. varieties

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Abstract

Durio zibethinus L. (durian) belongs to the Malvaceae family. It is known as the "King of Tropical Fruit" because of its unique characteristics. The edible part of durian, however, is only about 33% of the fruit while the non-edible parts such as the seed and peels (rinds) are considered as fruit waste responsible for environmental pollution. Thus, the present study was carried out to compare the percentage yields and volatile components from methanol extract and essential oils of the peels of four varieties of durian (Raja Kunyit [D197], Hajah Hasmah [D168], Sultan [D24], and Golden Bun [D13]). The antimicrobial activity of all the extracts and their volatile chemical constituents were also evaluated. Cold maceration was used for the solvent (methanol) extraction. The essential oil extraction was carried out using hydro-distillation and solvent-free microwave extraction (SFME) methods. The antimicrobial activity was evaluated against selected microbes using the well diffusion method while the characterization of chemical constituents in the essential oils and crude methanolic extracts was carried out using gas chromatography-mass spectrometry (GC–MS). The highest yields of essential oils were obtained from D24 which were 0.030% and 0.014% from SFME and hydro-distillation extraction, respectively, while the highest and most significant ($p < 0.05$) yield of methanol extract (8.79%) was obtained from D197. From the GC–MS analysis, butanoic acid was the major compound in the essential oil of durian peels in the four varieties of durians evaluated. Besides butanoic acid, 1-tridecene, 1-pentadecene, and 1-heptadecene were also present in the four varieties. The D168 possesses strong activity against three bacteria (*Bacillus subtilis*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*). More novel extraction techniques, bioactivity assays, and characterization are, however, recommended to further explore the potential benefits of durian peels.

Keywords *Durio zibethinus* L. · Antimicrobial · Essential oil · Hydro-distillation · Solvent-free microwave extraction

Highlights
- The peels of *Durio zibethinus* L. (durian) can be bioconverted into an antimicrobial agent.
- D24 durian variety yields a high amount of essential oils.
- Butanoic acid is a major compound in the essential oil of durian peels.
- Solvent-free microwave extraction method is more attractive for essential oil extraction.

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1 Introduction

Durio zibethinus L. otherwise referred to as "durian" belongs to the Malvaceae family. Durian is believed to be a native fruit of Southeast Asia, mainly Malaysia, Indonesia, and Thailand. Durian is entitled "King of Tropical Fruit" because of its unique characteristics like a formidable thorn, strong odor, and large size [19, 21, 33]. In Malaysia, the Jabatan Pertanian (Ministry of Agriculture and Food Industries) had registered all the varieties of durian being cultivated since 1934 until date. The thirteen popular varieties commonly cultivated by most of the durian producers in Malaysia are Sultan (D24), Kop Kecil (D99), Chanee (D123), Berserah (D145), Kan Yau (D158), Mon Thong (D159), Hajjah Hasmah (D168) or known as IOI, Tok Litok (D169), Golden Bun (13), Udang Merah (D175), Malaysian

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Agricultural Research and Development Institute potential hybrid durian (MDUR) 78 (D188), MDUR 79 (D189), MDUR 88 (D190), and Raja Kunyit (D197) also known as Musang King [46]. All the varieties have good quality in terms of texture, odor, color, and taste that make them enticing to consumers. The high resistance of the various durian varieties to disease largely contributes to their high production yields. However, about one-third of the fruit is edible while the non-edible part such as the seeds and peels (rinds) are generally considered as fruit waste [18]. The peel makes up 60% to 70% of the durian fruit [28]. The durian peel waste was about 133,688 tonnes in 2006 and 171,303.9 tonnes in 2013, thus, portends serious environmental threats especially to local communities [31] (Choon et al. 2016). To address this concern, readily available bioextraction techniques are suggested for the utilization of the wastes and their bioconversion into value-added and beneficial materials. One of such approaches is the targeted recovery of bioactive constituents that are valuable to food as well as non-food industries such as bio-fuel, health, pharmaceutical, and cosmetic industries [4, 6, 7, 12, 30, 42]. Natural products are highly beneficial as antioxidants and antimicrobial, anti-inflammatory, and anticancer agents [7, 47, 48]. The presence of alkaloids, anthraquinones, saponins, flavonoids, terpenoids, and phenolics in the crude ethanolic extracts of the rind and seeds of durian makes the plant sustainable sources of natural antioxidant and cytotoxic compounds [9].

Admittedly, there has been some reported information related to the bioactive constituents and antimicrobial activity of various durian parts [11, 14, 15, 19, 36, 38, 41, 44]. However, the peels are still considered agricultural wastes [20, 23, 26, 33].

Hence, the current study was aimed at evaluating the potential waste-to-wealth value of durian rinds by investigating the yields and antimicrobial activity of the essential oils and methanol extracts from the peels (rinds) of four varieties of durian (D197, D168, D24, and D13). The volatile constituents that are thought to be responsible for the biological activities were also elucidated using a gas chromatography-mass spectrometer (GC–MS) analytical technique. Nevertheless, more novel extraction techniques, bioactivity assays, and high-throughput characterizations of durian peels are recommended to further explore their potential benefits.

The uniqueness of the current work involves the comparison of the essential oils, crude extract yields, and the antibacterial activity among four different varieties of durian peels as well as the application of green chemistry and engineering following the adoption of energy-efficient and environmentally friendly extraction techniques to mitigate the energy cost and impact of chemicals on human health. Most conventional methods either use organic solvent or aqueous solvent with a longer extraction time (hydro-distillation), thereby leaving some toxic solvent residues or may degrade the oil quality. Clean and green extraction methods, however, are not only free from toxic solvents but also offer more natural products especially in essential oil industries.

2 Materials and methods

2.1 Chemicals

All chemicals were purchased from Sigma–Aldrich (Chemie, Steinheim, Germany) and Merck (Darmstadt, Germany) while all solvents used were either analytical or chromatographic grade.

2.2 Sample collection

The *D. zibethinus* L. peels were collected at durian stalls SS2, Petaling Jaya, Selangor, Malaysia. The four varieties of *D. zibethinus* peels evaluated in this study were D197, D24, D168, and D13. All the samples were collected between 1 April 2019 and 1 September 2019.

2.3 Extraction

Three different extraction procedures were employed [48]. The details of the procedures are itemized as follows:

I. Maceration

Five hundred grams of fresh *D. zibethinus* L. peels was cut into small pieces and soaked in methanol for 72 h in a conical flask. The samples were sonicated for 2 h every day. After 72 h, the samples were filtered using cotton wool. The soaking step was repeated consecutively three times. Then, the pooled extracts were collected, filtered through a filter paper (Whatman 1, cat no. 1001-150), and concentrated under reduced pressure at 50 ± 5 °C on a rotary evaporator to obtain a dark semi-solid extract.

II. Solvent-free microwave extraction (SFME)

Five hundred grams of fresh *D. zibethinus* L. was heated using a fixed power of 500 W for 30 min under atmospheric pressure in the presence of 50 mL ultrapure water to prevent the sample from burning very fast. The extraction was repeated three times. The oil was separated from the condensate using liquid-liquid extraction with 450 mL of ethyl acetate. The resulting oil was first dried over anhydrous sodium sulfate to remove any water molecule present. Then, the oil extract was concentrated under reduced pressure at 50 ± 5 °C on a rotary evaporator to obtain the essential oil.

III. Conventional hydro-distillation

Five hundred grams of *D. zibethinus* L. samples was subjected to the hydro-distillation technique using the Dean-Stark apparatus. The samples were placed in a 5-L round bottom flask with the addition of ultrapure distilled water and were heated in an isomantle for at least 4 h. The steam containing oil was directed to a condenser which condensed the oil into the reverse Dean-Stark apparatus. The oil was separated from the condensate using liquid-liquid extraction with 450 mL of ethyl acetate. The resulting oil was first dried over anhydrous sodium sulfate to remove any water molecule present. Then, the oil extract was concentrated under reduced pressure at 50 ± 5 °C on a rotary evaporator to obtain the essential oil.

2.4 Bacterial and fungal strains

Muller-Hinton agar and potato dextrose agar were used for the culturing of the bacterial and fungal stock cultures, respectively. The antimicrobial activity was studied against four bacteria: two Gram-positive strains (*Staphylococcus aureus* (ATCC 25,923) and *Bacillus subtilis* (B145)) and two Gram-negative strains (*Pseudomonas aeruginosa* (ATCC27853) and *Escherichia coli* (a clinical isolate)). Meanwhile, the two fungal strains involved in this study were *Candida albicans* (C2213) and *Aspergillus niger* (A121). All the fungi strains were collected from the Institute for Medical Research (IMR), Kuala Lumpur, while the bacteria strains were collected from the Microbiology Laboratory, Medical Faculty of the Universiti Putra Malaysia.

2.5 Antimicrobial activity

The antibacterial and antifungal assays were carried out using the well diffusion technique [8]. The methanolic extract was used at a concentration of 10 mg/mL while the essential oils and standard drugs were used at 1 mg/mL. The evaluation of the antimicrobial activity was done by determining the inhibition zone diameter after overnight incubation of the plates at 37 °C for 24 h (for antibacterial assay) and 25 °C for 48 h (for antifungal assay). Amoxicillin and streptomycin were used as positive controls for bacteria while nystatin and ketoconazole were used as positive controls for fungi. Dimethyl sulfoxide was used as a negative control. The minimum inhibitory concentration (MIC) of each extract was determined with the broth microdilution assay using 96-well flat-bottom microplate. Serial dilutions of the extracts and standard compounds ranging from 500 to 0.488 µg/mL were used for the assay. Then, 20 µL of an aqueous solution of 2,3,5-triphenyl tetrazolium chloride (TTC, 5 mg/mL) was added to each sample. The mixture was incubated for 1 h at 37 °C. Microbial growth was indicated by the appearance of pink color. The MIC value was identified as the lowest concentration that remained colorless. The minimum bactericidal concentration (MBC) for bacteria and minimum fungicidal concentration (MFC) for fungi were also determined.

2.6 Chemical profiling using gas chromatography-mass spectrometry (GC–MS)

The gas chromatography-mass spectrometer (GC–MS) column used was RTX-5MS fused-silica capillary column (30 mm × 0.25 mm i.d.; 0.25-µm film thickness) using helium as the carrier gas [48]. The analysis was run at a constant pressure of 100.0 kPa. The splitless mode was employed for the injection at a temperature of 300 °C. The oven temperature was ramped from 40 to 160 °C (5-min hold) at a rate of 4 °C/min and 160–280 °C (15-min hold) at 5 °C/min (rate). The total run time for each of the samples was around 74 min. The GC–MS interface temperature was set to 280 °C. MS mode was employed during analytical scanning from 45 to 500 atomic mass units (amu). The ion source temperature was set to 280 °C. The identification of the peaks was conducted against the National Institute of Standard and Technology Mass Spectral Library (NIST08 and 08 s) as well as PubChem©.

2.7 Statistical analysis

The data on the extraction and antimicrobial assays were represented as the average values of three replicates. Only the average values were, however, presented due to similarities in the results obtained. The data were analyzed using one-way ANOVA and Tukey post hoc test (SPSS 14.0) to determine the significant differences among samples. The significance level was set at $p < 0.05$.

3 Results

3.1 Yields of methanol and essential oil extracts

Each sample (500 g) of the four *D. zibethinus* L. varieties was extracted using maceration (methanol), solvent-free microwave extraction, and hydro-distillation extraction methods. The percentage yield was estimated using the equation below:

$$\%\text{Yield} = \frac{\text{Yield(g)}}{500\text{g}} \times 100 \quad (1)$$

The weights and percentage yields of the methanol extracts and essential oils are shown in Table 1. The highest yield of essential oil was obtained from the D24 variety,

Table 1 Yield of methanol extracts and essential oils from four different varieties of *D. zibethinus* L

D. zibethinus L. varieties	MeOH extract	Hydro-distillation extraction	SFME
D197	43.94 g (8.788%)^{a}	0.0617 g (0.012%)^{a}	0.1388 g (0.028%)^{ab}
D168	28.83 g (5.766%)^{c}	0.0693 g (0.014%)^{a}	0.1080 g (0.022%)^{c}
D24	28.07 g (5.614%)^{c}	0.0711 g (0.014%)^{a}	0.1495 g (0.030%)^{a}
D13	35.04 g (7.008%)^{b}	0.0662 g (0.013%)^{a}	0.1276 g (0.026%)^{b}

SFME solvent-free microwave extraction, *MeOH* methanol. (a–c) denote a significant difference among samples using Tukey's post hoc test (SPSS 14.0) at $p < 0.05$

giving 0.030% and 0.014% from SFME and the hydro-distillation extraction methods. Meanwhile, the highest yield of methanol extract (8.788%) was obtained from D197.

3.2 Antimicrobial activity

The results of the antimicrobial activity for all the tested extracts are shown in Table 2. According to the literature, zone of inhibition > 20 mm, 10–20 mm, 5–10 mm, and < 5 mm are considered very strong, strong, medium, and no response, respectively [35]. The D168 essential oil from the hydro-distillation method showed a strong and significant ($p < 0.05$) inhibition against the two Gram-positive strains (*B. subtilis* and *S. aureus*) with an inhibition zone of 15.30 mm each (Fig. 1, supplementary data, SD 1–SD 4). The essential oil of D24 from hydro-distillation also had strong and significant ($p < 0.05$) inhibition against *E. coli* with an inhibition zone diameter of 16.00 mm. Meanwhile, the methanol extract of D168 had the highest and significant ($p < 0.05$) diameter of inhibition zone of 17.00 mm among all the tested extracts against *P. aeruginosa*.

For *C. albicans*, the essential oil of D13 from SFME had the highest and most significant ($p < 0.05$) diameter zone of inhibition (13.30 mm) compared to other extracts while the essential oil of D197 from SFME exhibited the highest and most significant ($p < 0.05$) diameter zone of inhibition (21.30 mm) against *A. niger* with its activity highly comparable with the positive control (amoxicillin). The differences in the antimicrobial activity of the various extracts might be due to differences in the chemical constituents in each extract. It was also observed that there is no significant difference ($p > 0.05$) in the antimicrobial activity of the

Table 2 Diameters of inhibition zone of methanol extracts and essential oils from four varieties of durian

Extraction method	D. zibethinus varieties	Bacteria strains (mm)				Fungi strains (mm)	
		BS	SA	EC	PA	AN	CA
SFME	D197	15.00^{c}	14.40^{c}	11.70^{d}	12.00^{d}	21.30^{b}	12.30^{c}
	D168	15.00^{c}	15.00^{c}	12.70^{d}	14.70^{c}	10.70^{d}	11.00^{d}
	D24	13.70^{d}	13.30^{d}	11.00^{d}	14.00^{c}	10.70^{d}	11.70^{d}
	D13	11.30^{e}	11.70^{e}	11.70^{d}	13.00^{d}	11.00^{d}	13.30^{c}
Hydro-distillation	D197	12.70^{e}	12.00^{d}	11.30^{d}	12.00^{d}	10.30^{d}	12.70^{c}
	D168	15.30^{c}	15.30^{c}	12.30^{d}	14.00^{c}	10.70^{d}	11.30^{d}
	D24	14.70^{c}	12.40^{d}	16.00^{b}	13.70^{c}	11.70^{d}	11.70^{d}
	D13	12.00^{e}	11.00^{e}	11.00^{d}	12.00^{d}	13.00^{c}	12.00^{c}
Maceration (methanol)	D197	11.00^{e}	12.70^{d}	12.70^{d}	12.00^{d}	11.30^{d}	11.70^{d}
	D168	12.30^{e}	12.00^{d}	13.30^{c}	17.00^{b}	10.70^{d}	10.70^{d}
	D24	11.30^{e}	12.40^{d}	13.70^{c}	14.00^{c}	12.00^{c}	11.30^{d}
	D13	15.00^{c}	12.70^{d}	14.30^{c}	12.00^{d}	10.70^{d}	11.70^{d}
Streptomycin		25.30^{b}	23.70^{a}	23.30^{a}	23.70^{a}	ND	ND
Amoxicillin		36.30^{a}	19.70^{b}	14.30^{c}	22.00^{a}	ND	ND
Nystatin		ND	ND	ND	ND	28.00^{a}	34.70^{a}
Ketoconazole		ND	ND	ND	ND	24.70^{a}	19.30^{b}

ND, not determined. *BS*, *Bacillus subtilis* (B145); *SA*, *Staphylococcus aureus* (ATCC 25,923); *PA*, *Pseudomonas aeruginosa* (ATCC27853); *EC*, *Escherichia coli* (a clinical isolate); *CA*, *Candida albicans* (C2213); *AN*, *Aspergillus niger* (A121). (a–e) denote a significant difference among samples using Tukey's post hoc test (SPSS 14.0) at $p < 0.05$.

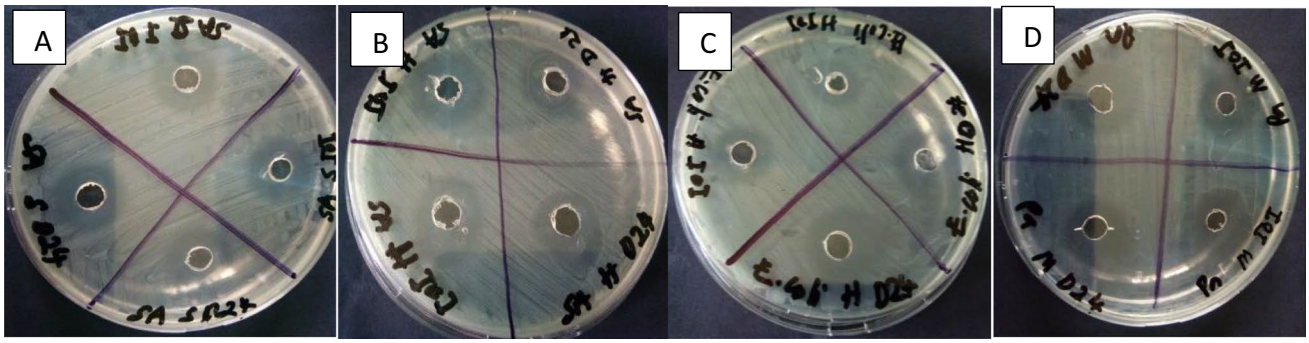

Fig. 1 Antimicrobial activity from selected plates. **A** *Staphylococcus aureus* with D168 extracted using SFME. **B** *Staphylococcus aureus* with D168 extracted using hydro-distillation. **C** *Escherichia coli* from D24 extracted from hydro-distillation. **D** *Pseudomonas aeruginosa* from D168 methanol extract

essential oils from SFME and hydro-distillation for some of the durian varieties.

Samples with a diameter of inhibition zone more than 15.00 mm were selected and further evaluated for MIC (Table 3) and MBC (Table 4) tests. The MIC values against the two Gram-positive bacteria for D168 essential oil extract from SFME and hydro-distillation were the same (62.50 µg/mL). However, there were differences in MBC values for both essential oils against *B. subtilis* and *S. aureus* which were 125.00 µg/mL and 250.00 µg/mL, respectively. The MIC and MFC results obtained from the antimicrobial activity against the two fungi strain (*C. albicans* and *A. niger*) are also presented in Tables 3 and 4, respectively. The essential oils of D197 from SFME had MIC and MBC values of 31.25 µg/mL and 62.50 µg/mL, respectively, against *A. niger*.

3.3 Gas chromatography-mass spectrometry (GC–MS)

The phytochemical analysis of the volatile components (essential oils) was performed using GC–MS for all the extracts (supplementary data, SD 5–SD 16). The comparison of the major constituents present in each extract is shown in Table 5. All compounds with SI (selectivity index) above 80% were assigned with a compound name while others with SI less than 80% were labeled as "unknown" when the mass spectrum was compared with the NIST library. Four compounds (1-dodecene, 1-tridecene, 1-pentadecene, and 1-heptadecene) belonging to the family of acyclic alkenes were found in almost all the essential oils extracted from SFME and hydro-distillation. Meanwhile, butanoic acid was found in all the essential oil extracts as the major component

Table 3 Minimum inhibitory concentration (MIC) of highly active extracts and standard drugs against selected microbes

Extraction method	D. zibethinus varieties	Bacteria strains (µg/mL)				Fungi strains (µg/mL)	
		BS	SA	EC	PA	AN	CA
SFME	D197	125.00^{a}	ND	ND	ND	31.25^{b}	ND
	D168	62.50^{b}	62.50^{a}	ND	ND	ND	ND
Hydro-distillation	D168	62.50^{b}	62.50^{a}	ND	ND	ND	ND
	D24	ND	ND	125.00^{a}	ND	ND	ND
Maceration (methanol)	D168	ND	ND	ND	125.00^{a}	ND	ND
	D13	125^{a}	ND	ND	ND	ND	ND
Streptomycin		3.91^{c}	7.81^{b}	1.95^{c}	31.25^{c}	ND	ND
Amoxicillin		0.98^{c}	62.50^{a}	7.81^{b}	62.50^{b}	ND	ND
Nystatin		ND	ND	ND	ND	3.91^{c}	0.97^{b}
Ketoconazole		ND	ND	ND	ND	250.00^{a}	125.00^{a}

ND, not determined. *BS*, *Bacillus subtilis* (B145); *SA*, *Staphylococcus aureus* (ATCC 25,923); *PA*, *Pseudomonas aeruginosa* (ATCC27853); *EC*, *Escherichia coli* (a clinical isolate); *CA*, *Candida albicans* (C2213); *AN*, *Aspergillus niger* (A121). (a–c) denote a significant difference among samples using Tukey's post hoc test (SPSS 14.0) at $p < 0.05$

Table 4 Minimum bactericidal concentration (MBC) and minimum fungicidal concentration (MFC) of highly active extracts and standard drugs against selected microbes

Extraction method	D. zibethinus varieties	Bacteria strains (µg/mL)				Fungi strains (µg/mL)	
		BS	SA	EC	PA	AN	CA
SFME	D197	250.00[b]	ND	ND	ND	62.50[b]	ND
	D168	125.00[c]	250.00[b]	ND	ND	ND	ND
Hydro-distillation	D168	125.00[c]	250.00[b]	ND	ND	ND	ND
	D24	ND	ND	250.00[a]	ND	ND	ND
Maceration (methanol)	D168	ND	ND	ND	500.00[a]	ND	ND
	D13	500.00[a]	ND	ND	ND	ND	ND
Streptomycin		15.63[d]	31.25[c]	7.81[c]	250.00[b]	ND	ND
Amoxicillin		15.63[d]	500.00[a]	31.25[b]	500.00[a]	ND	ND
Nystatin		ND	ND	ND	ND	15.63[c]	0.98[b]
Ketoconazole		ND	ND	ND	ND	> 500[a]	500.00[a]

ND, not determined. *BS*, *Bacillus subtilis* (B145); *SA*, *Staphylococcus aureus* (ATCC 25,923); *PA*, *Pseudomonas aeruginosa* (ATCC27853); *EC*, *Escherichia coli* (a clinical isolate); *CA*, *Candida albicans* (C2213); *AN*, *Aspergillus niger* (A121). (a–c) denote a significant difference among samples using Tukey's post hoc test (SPSS 14.0) at $p < 0.05$.

Table 5 Major chemical constituents analyzed by GC–MS in each extract

No	Compound name	Solvent-free microwave extract				Hydro-distillation extract				Methanol extract			
		D197	D168	D24	D13	D197	D168	D24	D13	D197	D168	D24	D13
1	Butanoic acid	√	√	√	√	√	√	√	√				
2	Phenol	√						√					
3	1-Dodecene		√	√	√	√	√	√	√				
4	1-Tridecene		√		√	√	√	√	√				
5	1-Pentadecene		√	√	√	√	√	√	√				
6	1-Heptadecene		√	√	√	√	√	√					
7	Caprolactam						√				√	√	√
8	Heneicosane		√				√	√	√				
9	Glycerin									√	√	√	√
10	1,4-Dioxane									√	√	√	√
11	Hexadecanoic acid					√		√		√	√		
12	Propane										√	√	√
13	Trimethylene borate									√		√	√
14	Isopropyl myristate		√				√	√			√		
15	Heptadecane	√											
16	1-Heneicosanol		√		√	√							
17	Ethanone		√		√								
18	Diethyl phthalate					√		√	√				
19	n-Hexadecanoic acid							√	√	√	√		

in all the extracts. The other two compounds found in all the methanol extracts were glycerin and 1,4-dioxane.

4 Discussion

The annual production of durian, like other tropical fruits, has been on the rise in the last two decades [46]. The increase in fruit production, however, also increases agricultural waste generation. As a concern for the environment, numerous researches have been carried out to utilize these agricultural wastes for their possible conversion to value-added materials [14, 18, 41] (Choon et al. 2016). The durian peel is being used as a low-cost bio-sorbent to remove dye used in the textile industry [34]. Biochar produced from pyrolyzed durian shells is also a promising solid fuel precursor [42]. The phytochemical investigation of durian peel has also contributed to the production of

pectin. Pectin is a fiber found in fruits and used as a medicine [29]. Durian peel contains a high content of polyphenols and protein and low content of fat, and is rich in mineral elements such as iron and magnesium [9, 11, 23, 33, 36, 38, 49]. Methanol is a commonly used extraction solvent due to its high polarity which could produce high extraction yields [5, 19, 41]. Charoenkiatkul, Thiyajai, & Judprasong [14] have also reported the extraction of durian leaves with ethanol.

The novelty of the current work includes the adoption of a cost-efficient, energy-efficient, and environmentally friendly extraction method as well as the application of green chemistry and engineering. The study also compares the essential oils and crude extract yields, and the antibacterial activity of four different varieties of durian peels. The adoption of clean and green extraction methods offers more natural products besides being free from toxic solvents [39]. Though both SFME and hydro-distillation methods are applied for the extraction of essential oils from medicinal and aromatic plants [24, 39, 48], SFME is a more promising and greener extraction technique. The determination of the optimum extraction condition is essential as it affects the biological activities and the nature of the chemical constituents [43]. Though the methanol extract gave a higher yield than the essential oils, the essential oils, however, had a stronger and broader spectrum of antimicrobial activity compared to the methanol extract [1, 16]. The methanolic extracts contained less volatile compounds as compared to the essential oils. In other words, the methanolic extracts contain both volatile and non-volatile components. Ang, Nalda, & Sabejon [9] reported non-volatile components such as alkaloids, anthraquinones, saponins, flavonoids, terpenoids, and phenolics in the crude ethanolic extracts of the rind and seeds of durian.

The results of the antibacterial activity of the methanolic extract and essential oils of durian peels of the current study are comparable to the work of Duazo, Bautista, & Teves [19] who had earlier reported the antibacterial activity of the methanolic extract of durian peels and seeds. Though Silva et al. [41] reported that the methanolic durian rind extract had no fungal activity against *Fusarium oxyporum* and *Aspergillus flavus*, on the contrary, an appreciable antifungal activity was found in the current study. Furthermore, the mixture of different classes of chemical compounds (volatile and non-volatile) in the methanol extract may lead to different interactions (synergistic or antagonistic) between active compounds and other secondary metabolites in the crude extract [22, 45]. The ethanolic extracts of durian leaves were reportedly active mostly on Gram-negative bacteria [14]. In the current study, however, mixed results were obtained among the four varieties of durian tested. The extraction techniques which mainly determine the composition of bioactive components are thought to be responsible [5, 48].

It is interesting to note that the yields of essential oils through SFME from all the four varieties evaluated in this study mostly double the yields from the hydro-distillation technique despite the long duration involved in the conventional hydro-distillation. This reinforces our plight to reduce the energy cost and chemical-related impact on human health through the application of green chemistry and engineering as well as the adoption of energy-efficient and environmentally friendly production methods. Natural products are rich in secondary metabolites and bioactive compounds which underlie their various bioactivities and potential applications [3, 7]. The characterization of natural products is important for the identification of the compounds and bioactive metabolites that might be responsible for their bioactivities. Durian peel is very rich in phenolic compounds, carbohydrates, and different classes of antioxidant compounds [36, 40]. Previously reported volatile compounds of durian peel are ketones, hydrocarbon ester, and acid [13]. Oleic acid, elaidic acid, petroselinic acid, and elaidic acid have also been found as major compounds in the essential oils of durian wood bark [2]. In the current study, butanoic acid is found to be a major compound in the essential oils of all the varieties of durian peels studied and, thus, thought to contribute to their antimicrobial activities. Butanoic acid is a short-chain fatty acid that is also an important metabolite with remarkable antimicrobial effects on most pathogenic bacteria and actively inhibits both Gram-positive and Gram-negative bacteria [17, 27]. Durian peels have also been used as a repellent and a wound healing, constipation, and menstruation regulation agent. The n-hexadecanoic acid found in durian's essential oil is known for its antibacterial and antifungal properties which might have also contributed to the antimicrobial activity of the durian's extracts in the present study. On the other hand, the durian's leaves have been used as an antipyretic as well as gelatin-based active packaging [26, 37]. Several studies have also reported the beneficial effects of n-hexadecanoic acid as an anti-inflammatory agent owing to its potent inhibition of cyclooxygenase-2, interleukin (IL-6), and tumor necrosis factor-α [10, 25, 32].

5 Conclusion

The present study showed that there is a high waste-to-wealth potential value for the durian peels. The D24 had the highest yield of essential oils, about 0.030% and 0.014% from the SFME method and hydro-distillation extraction method, respectively. D197 had the highest and most significant ($p < 0.05$) yield of methanol extract (8.79%). The solvent-free microwave extraction method seems to be more attractive than the conventional hydro-distillation method offering a higher yield with a lesser time and, thus, less energy. The analysis of the chemical constituents using

GC–MS showed that butanoic acid is a major compound in the essential oils extracted from durian peels from the four durian varieties studied. The durian peel extracts (essential oils and crude methanol extract) possess strong to moderate antimicrobial activities. Nevertheless, more novel extraction techniques, bioactivity assays, and high-throughput characterizations of durian peels are recommended to further explore their potential benefits.

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