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Physicochemical and Spectroscopic Characterissation of Malaysian Honeys for Potential Medicinal Applications

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Honey, a natural product from honeybees, is well-known for its therapeutic properties in managing various illnesses and health conditions. It contains a rich array of bioactive compounds, including polyphenols, flavonoids, amino acids, sugars, and essential minerals. In this light, rigorous quality control is essential to ensure the preservation and validation of these health-promoting attributes. In this study, multiple analytical techniques were employed to examine the quality of honey samples, including refractometry, electrical conductivity, UV-Vis spectroscopy, and FTIR-ATR analysis. As shown in the findings, the physicochemical parameters of all tested samples - pH (3.44 - 4.42), refractive index (1.47028-1.49037) water content (18.45% - 26.55%), viscosity (14439cP - 29661cP), and electrical conductance (97.71µS/cm - 769.56µS/cm), are within accepted quality standards and comparable to those of Manuka honey, indicating their potential for therapeutic applications. Additionally, UV-Vis and FTIR analyses revealed distinctive absorbance patterns that facilitated the differentiation of honey types and their geographical origins. Overall, this study underscores the importance of integrating physicochemical profiling with spectroscopic methods to assess honey quality for medicinal use comprehensively.

Keywords: Honey analysis; physicochemical properties; medicinal benefits; FTIR-ATR; UV-Vis

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Honey is a sweet, viscous fluid generated from floral nectar and stored inside the honey sacs of different types of bees. Since ancient times, honey has been acknowledged to be a functional food with medicinal and disease-protective properties [1]. Consequently, honey has been widely used worldwide for its health benefits [2, 3]. These benefits have also garnered an increase in research on honey in recent years. With the substantial growth of research on honey, there is now significant evidence supporting its role as a complementary and alternative medicine [4]. The use of natural medicines has been implemented and practiced for thousands of years to treat a wide range of diseases [5]. For instance, studies have scientifically proven that honey is therapeutically beneficial for treating urinary tract infections [6, 7], as an antidiabetic and antihyperlipidemic agent [8], as an antitumor agent [9], and for its wound-healing properties [10]. Honey was used in folk medicine for the treatment of burns, ulcers, wounds, and gastric diseases in ancient Greek, Egyptian, and Chinese medicine. Past studies have highlighted honey's properties, like nutritious, curative, effective in healing wounds, anti-inflammatory, an immune modulator, antidiabetic, and antibacterial [8, 11].

In general, honey is an exceptionally concentrated sugary solution that primarily consists of a complex variety of carbohydrates. In addition to carbohydrates, honey contains about 20% water, and other minor yet significant components, including phenolic acids, vitamins (pyridoxine, ascorbic acid, niacin), organic acids (acetic acid, gluconic acid), carotenoid-like compounds, volatile substances, flavonoids, amino acids, lipids, minerals, enzymes (catalase, glucose oxidase, phosphatases and invertase) and proteins [12]. Apart from these macro and micronutrients, honey contains various chemical elements, specifically minerals such as aluminium (Al), sodium (Na), magnesium (Mg), phosphorus (P), zinc (Zn), potassium (K), iron (Fe), lead (Pb), copper (Cu), arsenic (As), cobalt (Co) and calcium (Ca). While these constituents and elements can be found in almost all types of honey, their specific composition varies according to their geographical and botanical origin [2, 13]. In addition, honey contains methylglyoxal and hydrogen peroxide, which can inhibit

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microorganisms and bacteria, forming a good antibiotic material [6].

Notably, both the botanical and geographical origins of honey can be determined through a method known as melissopalynology. Melissopalynology is the study of the spectra of the pollens found in honey [14]. In this regard, the floral source of the honey can usually be identified by analysing the pollens present in the collected samples of honey [15]. As the origin of honey significantly influences its chemical constituents, this study will investigate how the physicochemical characteristics of honey from diverse sources affect its medicinal properties. Furthermore, numerous spectroscopic techniques have proven their efficiency in identifying the classification and authentication of honeys according to their entomological, geographical, and botanical origins. Spectroscopic techniques, such UV-Vis spectroscopy and Fourier-transform infrared (FTIR), offer rapid, cost-effective methods that can act as a fingerprinting approach to identify honey characteristics [16, 17].

Despite these reported benefits, there are currently no studies from Malaysia that specifically discuss the physicochemical and spectrophotometry characteristics of honey responsible for its medicinal uses. Understanding these characteristics is crucial, as they determine the quality and authenticity of the honey [18, 19]. Therefore, a deeper understanding of the physicochemical and spectrophotometry parameters that enhance honey's therapeutic properties is required to maximize its use in the medical field in the future. The proposed methodology for this study is based on the Harmonised Methods of the International Honey Commission (IHC) [20]. This study aims to characterise the physicochemical properties of different types of honey that are responsible for their medicinal uses. In addition, spectrophotometry analyses, specifically UV-Vis and FTIR, were employed to explore the different characteristics of honey obtained from different sources.

EXPERIMENTAL

Chemicals and Materials

Seven honey samples were included in the analysis. They are Archipelago Honey, Tualang Honey, Stingless Bee (Kelulut) Honey, Manuka Honey, Pollen Honey, Commercial honey sample 1, and Commercial honey sample 2. All honey samples are available in Malaysia and were sourced from different origins. The samples were analysed using analytical grade chemicals and reagents.

Sample preparation

Honey samples were prepared by thoroughly stirring the honey for ten minutes to ensure homogenisation. The heat was introduced to remove any crystallisation formed during storage with a thermostatic bath at 40 °C. Then, the samples were filtered using a syringe filter with a pore size of 0.2 µm to remove any extraneous particulate matter. The samples were stored in airtight containers at room temperature before further analysis [16, 21].

Moisture Content

A second homogenization was conducted after preparing the honey samples. Each homogenized sample was then poured into a 50 mL flask, which was sealed tightly to ensure it was airtight. The flask was placed in a water bath at a temperature ranging from 48 °C to 52 °C to dissolve any sugar crystals. The mixture was stirred again after cooling to room temperature. Before determining the water, the refractometer's prism was ensured to be dry and clean. The sample was applied evenly to cover the prism's surface right after homogenization. The refractive index (RI) reading was taken after two minutes. The corresponding moisture content was then checked using the appropriate chart [16, 22]. Finally, the water content was calculated based on the following formula:

$$W = \frac{1.73190 - \log (RI - 1)}{0.002243} \quad (1)$$

Where,

W= water content in g per 100 g honey

Electrical Conductivity

Each honey sample's electrical conductivity was measured using a Mettler Toledo conductivity meter [2, 23]. First, a 0.1 M KCl solution was freshly prepared for electrical conductivity determination. In a 1000 mL flask, 7.4557 g of KCl, previously dried at 130 °C, was thoroughly dissolved in freshly distilled water. Distilled water was then added to fill the flask to the mark. After determining the cell constant, the electrode was thoroughly rinsed with distilled water. A previously prepared sample was taken, and a quantity of honey equivalent to 20 g of anhydrous honey was dissolved in distilled water. This solution was transferred to a 100 mL volumetric flask, and distilled water was added to make up the volume. A 40 mL sample of this solution was placed in a beaker. The beaker was then placed in a water bath set at 20 °C. The remaining sample solution was used to rinse the conductivity cell thoroughly. The conductivity cell was then fully immersed in the sample solution. Once the temperature reached equilibrium, the conductance was recorded in mS. The electrical

conductivity of all honey samples was calculated using the formula below,

$$SH = K. G \quad (2)$$

SH = electrical conductance of the honey solution, µS/cm
K = cell constant, cm-1
G = electrical conductivity, mS

The result is expressed to the nearest two decimal places, using the unit of µS/cm.

pH and Free Acidity

The Mettler Toledo pH meter was calibrated at pH 3.0, 7.0, and 9.0. Using a 250 mL beaker, the honey samples, weighing 10 g, were dissolved in 75 mL of distilled water. The pH electrodes were put in the solution. It was then agitated with the magnetic stirrer, and the pH reading was recorded. The sample was titrated to pH 8.30 using 0.1 M NaOH within 120 seconds. The reading was set to the nearest 0.01 mL when a 10 mL burette was used. In writing the results, pH value was reported in two decimal places, while the free acidity was reported in one decimal place, in the unit of mEq or mM acid/kg honey [22, 23]. To obtain the free acidity, the following formula was used:

$$\text{Free acidity} = \text{volume in mL of 0.1 M NaOH} \times 10 \quad (3)$$

Mineral Analysis

The mineral concentrations in all samples were determined using the atomic absorption spectrometric method [19, 24]. Zinc (Zn), calcium (Ca), and magnesium (Mg) levels were determined using a Perkin Elmer® atomic absorption spectrometer while The concentrations of these elements in the sample were determined in µg/g. Furthermore, a 500 g/mL palladium solution was used as a chemical modifier for the identification of trace elements. Given that the concentration is threefold to the standard deviation of 10 blank samples, the detection limits for each example were determined. All specimens were then run in batches, with each batch containing two spiked specimens, a standard calibration curve, and a sample blank. Finally, five different concentrations for each element were analysed.

Viscosity

The viscosity of honey samples was measured using a Viscobasic Plus/Fungilab® viscometer [18, 25]. Each sample was tested with the suitable spindle size and rotation per minute (RPM) based on the honey's thickness. Three readings were taken for each sample, and the average value was calculated.

Ultraviolet-Visible Spectroscopy

100 µL solution of the honey sample was prepared by diluting pure honey with distilled water. Afterwards, the honey was submerged in the water for 60 minutes. Subsequently, the solution was vortexed, and both sample and standard solutions were filtered using a syringe filter with a pore size of 0.2 µm. The UV–Vis spectra were recorded in the range of 190 to 400 nm using a double-beam UV-Vis spectrophotometer (Shimadzu, UV-1800) with a resolution of 1 nm. All measurements were performed at room temperature (25 ± 1 °C) [1, 17].

Fourier Transform Infrared Analysis

FTIR spectra of the honey samples were recorded using a PerkinElmer FTIR Spectrum with attenuated total reflection (ATR). The spectra were detected with the MIR TGS (15000–370) cm-1 operating system. Approximately 0.05 mL (a drop) of each sample was scanned at 0.2 cm/s and 1 cm-1, covering the range from 4000 cm-1 to 550 cm-1 [16, 26].

RESULTS AND DISCUSSION

Moisture Content and Viscosity

The moisture content and viscosity of different honey samples are listed in Table 1. Moisture content is one of the crucial parameters in determining the quality of a honey, as it affects the stability of honey against granulation and fermentation [22]. High moisture content increases the risk of microbial spoilage. Manuka honey, Commercial sample 1, and Commercial sample 2 had the least water percentages, at 18.78 ± 1.12, 18.45 ± 1.94, and 18.57 ± 1.86, respectively. All within the Codex Alimentarius Standard (2011) [27], which recommends a maximum moisture content of 20% for honey.

Table 1. Moisture content and viscosity of honey samples.

	Refractive Index, RI Value	Water Content, W (%)	Viscosity (cP)
Archipelago Honey	1.48303	21.37 ± 1.48	14439 ± 175
Tualang Honey	1.47804	23.38 ± 0.96	13951 ± 457
Stingless Bee Honey	1.47028	26.55 ± 1.79	19815 ± 325
Manuka Honey	1.48953	18.78 ± 1.12	29661 ± 256
Pollen Honey	1.48067	22.32 ± 2.31	21130 ± 85
Commercial sample 1	1.49037	18.45 ± 1.94	22758 ± 344
Commercial sample 2	1.49007	18.57 ± 1.86	20278 ± 105

Results are presented as mean ± standard deviation (n = 3).

On the other hand, high viscosity provides a protective barrier to prevent infection. Manuka honey showed the highest viscosity (29661 ± 256 cP), while tualang honey had the lowest viscosity (13951 ± 457 cP). The viscosity of honey is influenced by moisture, temperature, and botanical origin. Honey is primarily composed of specific carbohydrates sugar including glucose, sucrose, and fructose [2, 3]. The thickness of the semisolid solution of honey results from the precipitation of glucose crystals in the sucrose solution with other constituents at room temperature. Importantly, honey is a hygroscopic material that can absorb water from the surrounding environment at room temperature. Honey needs to be kept in airtight containers to maintain its stability for its therapeutic benefit. The absorption of water can affect the temperature, colour, and viscosity of honey [2, 25].

Electrical Conductivity

Electrical conductance has been widely monitored in routine honey quality control. It is considered a good indicator of honey purity and botanical source. As shown in Table 2, Archipelago Honey (97.71 µS/cm) recorded the lowest conductivity values, while Manuka Honey was found to have the highest conductivity values (769.56 µS/cm). The results for all samples were reported below 800 µS/cm, in compliance with the Codex Alimentarius Standard [27].

Table 2. Electrical conductivity of honey samples.

	Electrical Conductivity, G (µS)	Electrical Conductance, SH (µS/cm)
Archipelago Honey	8.38	97.71
Tualang Honey	32.20	375.45
Stingless Bee Honey	57.47	670.10
Manuka Honey	66.00	769.56
Pollen Honey	28.70	334.64
Commercial sample 1	12.66	147.62
Commercial sample 2	12.21	142.37

Table 3. pH and free acidity of honey samples.

	pH	Acidity (mEq/kg)
Archipelago Honey	3.96	5.0
Tualang Honey	3.92	25.0
Stingless Bee Honey	3.44	93.0
Manuka Honey	4.42	7.0
Pollen Honey	3.96	17.0
Commercial sample 1	3.93	7.0
Commercial sample 2	4.31	7.0

Electrical conductivity is strongly linked to the concentration of organic acids and minerals present in honey. These components dissociate into ions when dissolved in water, enabling them to move freely and carry an electric current. As the concentration of minerals, organic acids, and proteins increases, so does the electrical conductivity, which is also associated with the honey's darker colour [24]. Consequently, measuring conductivity can help differentiate the floral sources of honey.

Interestingly, a clear linear relationship has been found between electrical conductivity and ash content, with increased ash and acid levels resulting in higher conductivity [23, 28]. Although conductivity measurements can serve as an indirect indicator of ash content, they are not exclusively influenced by it. Ash content can reflect environmental contamination and help identify the geographical origin of honey. However, other factors—such as storage duration, floral sources, and protein content—also influence honey's conductivity. Therefore, elevated conductivity values do not always signify higher ash levels [28].

pH and Free Acidity

The pH and free acidity of the samples are listed in Table 3. In general. Honey is mildly acidic with a pH of between 3.44 to 4.42. Furthermore, honey tends to have a lower pH for a longer shelf life and better stability, with a stronger ability to inhibit the growth of microorganisms. According to the Codex standard for honey, free acidity should not exceed 40 mEq/kg [27]. This study found that, except for the stingless bee honey sample, all samples showed free acidity levels within the normal range. It is worth noting that high acidity is a natural and unique trait of stingless bee honey due to its special composition, higher moisture content, and the presence of organic acids [29].

Table 4. Mineral content of honey samples.

	Concentration of Minerals (µg/g)		
	Zinc	**Calcium**	**Magnesium**
Archipelago Honey	2.06	73.42	32.67
Tualang Honey	2.62	68.83	29.91
Stingless Bee Honey	1.90	61.19	21.73
Manuka Honey	1.29	121.67	34.74
Pollen Honey	2.26	59.98	27.92
Commercial sample 1	0.48	32.61	13.95
Commercial sample 2	0.43	48.05	15.19

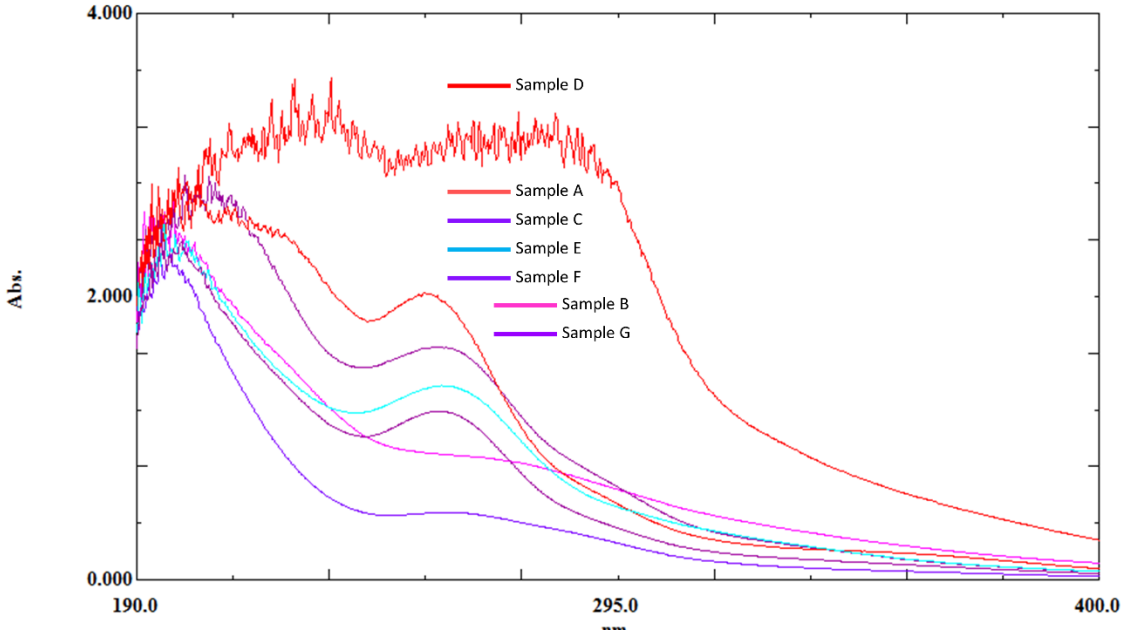

Figure 1. The raw absorption data of the honey sample. Sample: (A) Archipelago Honey, (B) Tualang Honey, (C) Stingless Bee Honey, (D) Manuka Honey, (E) Pollen Honey, (F) Commercial sample 1, (G) Commercial sample 2.

The pH of honey affects honey taste and aroma. The acidic content of honey, which is brought on by various nectar sources, includes lactic acid, citric acid, gluconic acid, formic acid, amino acids, and other organic acids. The pH can be used as a quality indicator, as adultered honey will have a different pH [19, 28]. According to Yadata [30], honey adulterated with inverted sugar has a lower pH, while honey adulterated with sugar syrup has a higher pH. Generally, low pH gives advantages in preventing microorganisms' growth and proliferation [23, 25]. High pH, along with high temperature and long storage period, leads to faster breakdown of fructose and formation of hydroxy-methylfurfural [21].

Mineral Analysis

The mineral content of different honey samples is listed in Table 4. Based on the mineral analysis, Tualang honey has the highest content of zinc (Zn), while Manuka honey contains the highest concentration of both calcium (Ca) and magnesium (Mg), in comparison to the other honey samples. All these minerals in honey are essential for the human body as they are components of various types of hormones and enzymes, and activate enzymes to regulate bodily processes [2].

Honey contains an abundance of mineral constituents that are crucial for the regulation of systems in the body of an individual. Generally, when taken in an appropriate dose, these minerals can be very advantageous to human health [25]. Consuming the right concentration, Ca is beneficial in treating and preventing osteoporosis, Zn improves immunity and acts as an antioxidant, while Mg is needed for the development of bone. Nevertheless, high concentrations of minerals can pose a risk to human health [2, 19, 31]. Assessing the elemental composition of honey is essential for evaluating its quality, as certain elements can pose health risks. The recommended daily dietary intake for adults is approximately 2500 mg for calcium (Ca), 12–15 mg for zinc (Zn), and 400–420 mg for magnesium (Mg) [31]. Honey samples available in Malaysia generally contain appropriate levels of these essential minerals, providing nutritional benefits with minimal risk of toxicity.

UV–Vis Spectra of the Honey Samples

The UV-Vis spectra of the honey samples are shown in Figure 1. UV-Vis spectroscopy is commonly used to analyse honey based on the position and intensity of absorbance peaks. All samples exhibited peak absorbance in the range of 230-310 nm, which is characteristic of honey's bioactive constituents. Notably, Manuka honey displayed the broadest and most intense absorbance peak among the honey samples, correlating with its higher concentration of nutritional compounds [34]. These spectral patterns align with those previously reported for honeys from various botanical and geographic origins, reinforcing the reliability of UV-Vis spectroscopy as a tool for differentiating honey types and assessing their quality and origin [1, 17].

Razavi & Kenari (2023) reported that authentic honey samples exhibit their highest absorbance peaks within the 220 to 310 nm range, a spectral signature commonly associated with genuine honey. This region corresponds to the presence of key bioactive compounds, such as phenolic acids and flavonoids,

which contribute significantly to honey's antioxidant properties [12, 17]. Similarly, a study on Indonesian honey samples reported peak absorbance intensities between 270 - 300 nm, attributed to compounds like salicylic, benzoic, and aryl-aliphatic acids, which are important constituents of honey. These compounds not only enhance the nutritional value of honey but also support its therapeutic potential. The consistency of these spectral findings across diverse botanical and geographical sources highlights the robustness of UV-Vis spectroscopy as a reliable method for verifying honey quality and authenticity [1, 17]. Nonetheless, UV-Vis spectroscopy has been effectively employed to detect adulteration in honey by measuring the characteristic peak formed. Adulterated samples often exhibit broader absorbance peaks between 250–340 nm, which are linked to added sugars and synthetic compounds formed during syrup production and adulteration processes [17].

FTIR Spectra of the Honey Samples

The FTIR spectra of the honey samples, recorded in the 4000–650 cm^{-1} spectral region, are shown in Figure 2. Honey typically exhibits five key spectral regions: 3000–2800 cm^{-1}, 1700–1600 cm^{-1}, 1540–1175 cm^{-1}, 1175–940 cm^{-1}, and 940–700 cm^{-1}. Across all samples, common functional group vibrations characteristic of honey were observed, including broad O–H stretching bands around ~3296 cm^{-1}, C–H stretching at ~2934 cm^{-1}, and C=O stretching near ~1643 cm^{-1}. According to Gok et al. [26], the 3000–2800 cm^{-1} region corresponds to C-H stretching vibrations in carbohydrates and O-H stretching in carboxylic acids.

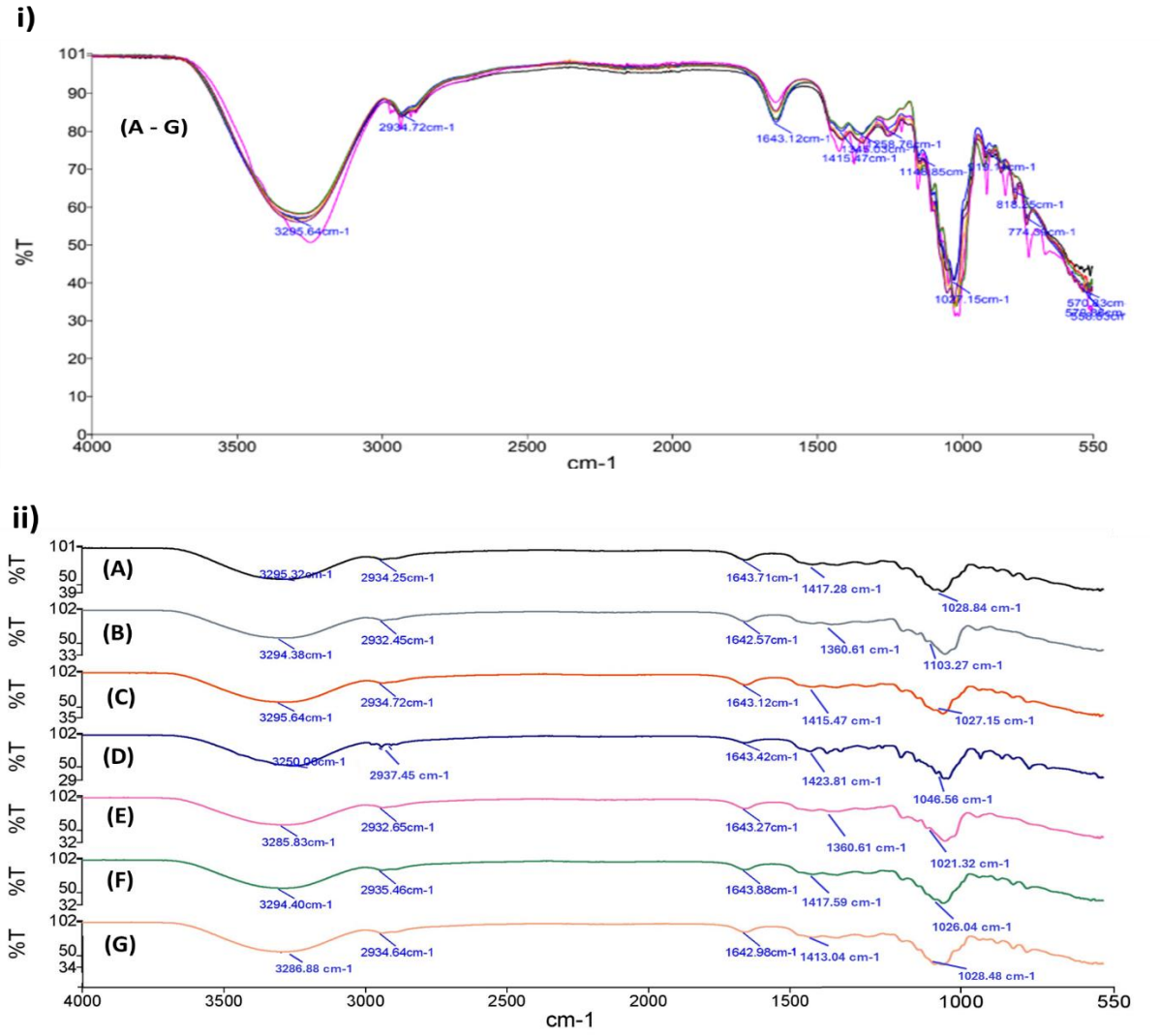

Figure 2 FTIR spectra of honey samples i) Overlay, and ii) Individual. (A) Archipelago Honey, (B) Tualang Honey, (C) Stingless Bee Honey, (D) Manuka Honey, (E) Pollen Honey, (F) Commercial sample 1, (G) Commercial sample 2.

This region is particularly significant as it reflects the presence of essential functional groups that contribute to honey's nutritional and therapeutic properties. The 1700–1600 cm^{-1} is associated with C=O stretching from carbohydrates and N-H bending from amide groups in proteins. This spectral zone is crucial for identifying protein content and carbonyl compounds, both play important roles in honey's antioxidant activity.

The (1540–1175 cm^{-1}) and (1175–940 cm^{-1}) regions result from the stretching of C-O, C-H, and C-C bonds in carbohydrates. These regions are indicative of the complex carbohydrate structures in honey, which include various sugars such as glucose and fructose. The presence of these sugars is essential for the energy-providing properties of honey. The (940–700 cm^{-1}) region is characteristic of ring vibrations and C-H bending in carbohydrates. This region helps in identifying the specific types of carbohydrates present in honey, which can vary based on the botanical origin of the honey. The different types and botanical origins of honey lead to variations in water, carbohydrates, and protein content, resulting in distinct spectral patterns for each sample [16, 26]. Significant variations in spectra from approximately 1500–750 cm^{-1} have been found, corresponding to major components of honey such as sucrose, glucose, and fructose. These variations are important for determining the quality and authenticity of honey, as well as for understanding its nutritional and therapeutic properties.

Regarding the quality analysis, the distinctive spectral patterns of both these UV-Vis and FTIR spectra can be used to identify honey samples. The overlay of UV-Vis and FTIR spectra shows variable absorbance that depends on the chemical composition of the honey. The chemical composition of honey includes various types of molecules present in small quantities, such as phenolic compounds, organic acids, enzymes, and vitamins. These different chemical constituents of honey combine to form unique spectral absorptions. Every substance has its absorption spectrum, and the wavelength affects its intensity. UV-Vis spectroscopy is particularly useful for identifying the presence of phenolic compounds and flavonoids, which are responsible for the antioxidant properties of honey. These compounds absorb light in specific regions of the UV-Vis spectrum, allowing for their detection and quantification. The variability in absorbance spectra can help differentiate between honey samples from different botanical and geographic origins, ensuring the authenticity and quality of the product [1, 17]. FTIR spectroscopy, on the other hand, provides detailed information about the functional groups present in honey. By analysing the specific absorption bands in the FTIR spectrum, it is possible to identify various organic acids, sugars, and other bioactive compounds. This technique is highly sensitive and can detect even minor differences in the chemical composition of honey, making it an invaluable tool for quality control and authentication [16, 21]. The UV–Vis and FTIR spectra are simple, rapid, and cost-efficient analysis tools for fingerprinting honey. Both of these spectroscopic techniques have been successfully used as quality control tools for analysing honey, including for detecting any adulteration in honey [17]. The UV-Vis spectroscopic has also been used to determine the chemical composition of various herbal ingredients without prior chromatography purification of chemical compounds. At the same time, FTIR is a robust and promising spectroscopic method for identifying functional groups present in honey [21, 26]. By utilizing both UV-Vis and FTIR spectroscopy, it is possible to obtain a comprehensive understanding of the chemical composition and quality of honey, ensuring that consumers receive a product that meets the highest standards of content.

The study found a large variation in the spectral results of Manuka honey, attributable to its numerous chemical constituents. Manuka honey, a medical-grade honey, has been extensively studied and now has numerous applications within a clinical setting [32, 33]. It contains a significant amount of small and trace constituents, such as methyl syringate and leptosin [32]. Additionally, Manuka honey exhibits high electrical conductivity, pH, and viscosity, resulting from its high mineral and organic acid content. The high electrical conductivity indicates its rich mineral content, while the presence of organic acids and other bioactive compounds influences its pH and viscosity. These properties not only enhance the therapeutic potential of Manuka honey but also serve as important indicators of its quality and authenticity.

The study observed that other honey varieties available in Malaysia have comparable physicochemical and spectroscopic properties to Manuka honey. Honey characteristics primarily depend on the botanical origin, which affects its chemical composition. However, these characteristics (moisture content, conductivity, and pH) can be improved during honey harvesting and manufacturing to enhance their stability and quality [16]. Currently, honey is used in clinical settings as a topical application for acute and chronic wounds, and no known bacterial resistance to honey has been reported [8, 11, 33]. In this light, further research is needed to investigate the anti-inflammatory, antioxidant, heavy metal toxicity and antibacterial activities of Malaysian honey for medicinal applications.

CONCLUSION

This study examined the physicochemical parameters of honey from Malaysia to explore their potential use in complementary and therapeutic medicine. It was found that the moisture content of the honey samples ranged from 18.45% to 26.55%, electrical conductivity ranged from 97.71 µS/cm to 769.56 µS/cm, free acidity ranged from 5mEq/kg to 93mEq/kg, and

viscosity ranged from 13951cP to 29661cP. Moreover, the physicochemical properties of all honey samples investigated in this study are comparable to Manuka honey and within the WHO-recommended range, indicating their suitability for medical purposes. Moreover, UV/Vis and FTIR spectroscopy provided a comprehensive overview of the chemical composition and various functional groups present in the honey. These techniques can be used to differentiate between different types and origins of honey, as each exhibits unique fingerprint absorbance patterns.

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The authors declare that they have no conflict of interest.

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