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Comparative study of bioactive compounds and biological activities among Thai monofloral honeys from different floral origins

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Abstract

The study compares the biological potential of six varieties of honey from different floral origins in Thailand, including longan (*Dimocarpus longan* Lour.), premium longan (raw honey derived from *Dimocarpus longan* Lour.), Siam weed (*Chromolaena odorata*), lychee (*Litchi chinensis* Sonn.), coffee (*Coffea arabica* L.), and Manuka (*Leptospermum scoparium*). Total phenolic content (TPC) and total flavonoid content (TFC) were determined, followed by the evaluation of antioxidant activities using ferric reducing antioxidant power (FRAP), 2,2-diphenyl-1-picrylhydrazyl (DPPH), and ascorbic acid equivalent antioxidant capacity (AEAC) assays. Quantitative analysis of phenolic and flavonoid compounds was performed using high-performance liquid chromatography (HPLC), with compound identification based on retention times of authentic standards. Antimicrobial activity, expressed as minimum inhibitory concentration (MIC), and basic physicochemical properties were also evaluated. Multivariate analyses, including principal component analysis (PCA) and Pearson correlation were applied to link the biochemical composition of honeys with biological activities. Manuka and premium longan honeys exhibited the highest phenolic and flavonoid levels and strong antioxidant capacities. Major compounds, including gallic acid, caffeic acid, quercetin, and catechin, showed significant correlations with TPC, TFC, and both antioxidant and antimicrobial activities. PCA grouped Manuka and premium longan honeys in a high-bioactivity cluster, closely associated with antioxidant variables and low MIC values, particularly against *Staphylococcus aureus* (7.5% w/v). Lychee honey showed high flavonoid content but limited antimicrobial activity, while coffee and conventional longan honeys displayed moderate activities. In contrast, Siam weed honey exhibited the lowest bioactive levels, consistent with its weak antioxidant and antimicrobial properties. Multivariate analyses confirmed that phenolics and flavonoids are the main drivers of honey bioactivities. These findings highlight Thai premium longan honey as a promising bioresource for functional food and cosmeceutical development, supporting its potential to enhance local economic value.

Keywords Thai monofloral honey, Phenolic compounds, Flavonoids, Antioxidant activity, Antimicrobial activity, HPLC



1 Introduction

The market for healthy foods and natural cosmetics has seen accelerated growth, particularly in honey-based products and skincare, driven by the concepts of clean beauty and sustainability. A recent report projected that the global honey market will expand from USD 9.01 billion in 2022 to USD 13.57 billion by 2030, with a compound annual growth rate of approximately 5.3% [1]. Key driving factors include enhanced health awareness, increasing consumer demand for safe and natural products, and a growing trend toward reduced use of synthetic chemicals [2]. These trends underscore the importance of investigating honey as a raw material that can address both efficacy and sustainability demands in functional food and natural cosmetic applications.

Honey is a natural product with a complex composition, including sugars, enzymes, organic acids, and bioactive compounds such as polyphenols and flavonoids. These compounds play critical roles as antioxidants, antimicrobials, and anti-inflammatory agents and have established honey as a promising raw material for functional food and natural cosmetic development [3]. Phenolic and flavonoid compounds are considered the main active constituents contributing to honey bioactivities, particularly antioxidant and antimicrobial effects [4]. Their presence and concentration are strongly influenced by floral origin, resulting in distinct biological profiles among different honey varieties. Different plant species produce characteristic secondary metabolites that are transferred from nectar to honey, contributing to variations in phenolic and flavonoid composition and consequently influencing antioxidant and antimicrobial properties [3, 4].

The honeys investigated in this study originate from several floral sources commonly found in Thailand, including longan (*Dimocarpus longan* Lour.), Siam weed (*Chromolaena odorata*), lychee (*Litchi chinensis*), and coffee (*Coffea arabica* L.), as well as Manuka honey derived from *Leptospermum scoparium*. These plants are known to contain diverse phytochemicals such as phenolic acids, flavonoids, and other antioxidant compounds, which can influence the chemical composition and biological activities of the resulting honeys [3, 5]. Consequently, monofloral honeys derived from different botanical sources may exhibit distinct functional properties. The honeys investigated in this study were produced by *Apis mellifera*, the predominant honeybee species used in commercial honey production in Thailand [5].

The antioxidant activity of honey is primarily attributed to phenolic acids and flavonoids, which act through electron or hydrogen atom donation and metal chelation mechanisms that inhibit oxidative reactions [6]. These phenolic compounds may exert antioxidant activity through several mechanisms, including hydrogen atom transfer (HAT), single-electron transfer (SET), and free radical scavenging processes that neutralize reactive oxygen species and stabilize radical intermediates [3, 6]. By chelating transition metals such as Fe^{2+} and Cu^{2+} , these compounds suppress Fenton reactions, thereby reducing lipid peroxidation and slowing cellular deterioration [3]. In addition to phytochemical composition, physicochemical factors including low pH, high sugar concentration, and low water activity contribute synergistically to the stability and effectiveness of honey's bioactive properties [7, 8]. These physicochemical parameters are also widely used as key indicators of honey quality and to assess compliance with international standards, including international standards such as the Codex Alimentarius.

Honey exhibits antimicrobial activity through both peroxide-based and non-peroxide-based mechanisms. The peroxide-based mechanism involves hydrogen peroxide (H_2O_2)

generation by glucose oxidase, which can damage microbial cell walls and inhibit enzymatic activity; however, this pathway is heat-sensitive, making raw honey generally more potent than processed honey [8, 9]. In contrast, Manuka honey demonstrates strong non-peroxide antimicrobial activity, primarily attributed to methylglyoxal (MGO), which disrupts bacterial cell structures and interferes with cellular metabolism, including in multidrug-resistant strains [7, 8, 10]. Additionally, osmotic effects arising from low pH and high sugar concentration further reinforce honey's antimicrobial efficacy [11]. Beyond these general mechanisms, phenolic acids and flavonoids contribute to antimicrobial activity by disrupting membrane integrity, denaturing proteins, and inhibiting quorum sensing and enzymes involved in cell wall biosynthesis, thereby reducing biofilm formation and microbial growth [4, 12]. Consequently, analysis of specific phenolic and flavonoid compounds and their relationships with biological activities is essential for understanding honey's bioactive potential [13, 14].

Several studies have reported the physicochemical properties and antioxidant activity of Thai honeys, particularly longan honey. For instance, Hempattarasuwan and Settachaimongkon [5] demonstrated that botanical source and processing conditions significantly influence the physicochemical characteristics and antioxidant activity of honey produced in northern Thailand. However, existing studies have mainly focused on selected floral sources or basic antioxidant parameters, while comprehensive integration of quantitative phenolic–flavonoid profiling with antimicrobial activity and multivariate statistical analysis remains limited. In particular, systematic evaluation linking individual phenolic and flavonoid compounds with both antioxidant and antimicrobial activities across different Thai monofloral honeys, in comparison with reference honey such as Manuka, has not been fully explored.

Therefore, this study aimed to evaluate the biological potential of Thai honeys from different floral origins in comparison with Manuka honey by assessing physicochemical properties and sugar compositions, quantitative profiles of selected phenolic and flavonoid compounds, antioxidant activities (FRAP, DPPH, AEAC) and bioactive compound contents (TPC, TFC), and antimicrobial activity. Relationships between chemical composition and bioactivity were further elucidated using Pearson correlation and principal component analysis (PCA). This integrated approach provides a systematic perspective supporting the potential of Thai honeys, particularly premium longan honey, as valuable raw materials for functional food and natural cosmetic applications.

2 Materials and methods

2.1 Chemicals and reagents

Analytical standards including gallic acid, catechin, quercetin, caffeic acid, and other phenolic compounds were obtained from Sigma-Aldrich (St. Louis, MO, USA). Folin–Ciocalteu reagent, aluminum chloride (AlCl_3), 2,4,6-tripyridyl-s-triazine (TPTZ), ferric chloride (FeCl_3), and 2,2-diphenyl-1-picrylhydrazyl (DPPH) were used for antioxidant assays. Methanol, acetonitrile, and formic acid of HPLC grade were purchased from Merck (Darmstadt, Germany). All other chemicals and reagents were of analytical grade.

2.2 Honey samples

Six types of monofloral honey were used in this study: longan honey (*Dimocarpus longan* Lour.), premium longan honey (raw honey from *Dimocarpus longan* Lour.), Siam

weed honey (*Chromolaena odorata*), lychee honey (*Litchi chinensis* Sonn.), coffee honey (*Coffea arabica* L.), and Manuka honey (*Leptospermum scoparium*).

All Thai honey samples were produced by *Apis mellifera* and collected during the main flowering season between February and March 2023, with sampling conducted in the morning (08:00–10:00 h), from an authenticated local apiary in Chiang Mai, Thailand. Floral origin was identified based on the predominant flowering source during the harvesting period and producer certification. Monofloral classification followed commonly accepted criteria in honey research when pollen analysis is not available. For each honey type, three independent samples ($n=3$) were collected and analyzed. Manuka honey was obtained from a certified producer in New Zealand ($n=3$). All honey samples were stored at 4 °C in airtight containers until analysis.

2.3 Physicochemical properties and sugar compositions

Physicochemical analyses of honey samples were performed according to AOAC [15]. Total soluble solids (°Brix) were measured using a digital hand refractometer (ATAGO, Japan). Moisture content was determined by oven-drying at 105 °C for 2 h until constant weight. After drying, samples were cooled in a desiccator for 30–45 min and weighed until a constant weight was obtained. The pH of honey samples was measured using a calibrated pH meter (Mettler Toledo, Switzerland). All measurements were performed in triplicate.

The sugar composition of honey samples was analyzed using high-performance liquid chromatography (HPLC) (Shimadzu LC-20 A Series, Kyoto, Japan) according to the modified method of Alemayehu et al. [16]. Five grams of honey were dissolved in 10 mL of distilled water, thoroughly mixed, and allowed to stand overnight to ensure complete dissolution. The solution was then filtered through a 0.45 µm membrane filter prior to analysis. The injection volume was 20 µL. Separation was performed on a Zorbax NH₂ column (250 × 4.6 mm, 5 µm; Agilent Technologies, USA) maintained at 40 °C, using acetonitrile: water (85:15, v/v) as the mobile phase at a flow rate of 1.0 mL/min. Detection was carried out using a refractive index detector (RID). Quantification of glucose, fructose, and sucrose was performed using external calibration with authentic standards. Results were expressed as g/100 g honey, and each sample was analyzed in triplicate.

2.4 Quantitative analysis of phenolic and flavonoid compounds

The quantitative determination of phenolic and flavonoid compounds in honey samples was performed using high-performance liquid chromatography (HPLC) (Shimadzu LC-20 A Series, Kyoto, Japan) equipped with a diode array detector (DAD), modified from Sangta et al. [17]. Separation was carried out on an Ultra Aqueous C18 column (250 × 4.6 mm, 5 µm; RESTEK, Bellefonte, PA, USA). The mobile phase consisted of solvent A (formic acid: distilled water, 5:95, v/v) and solvent B (acetonitrile: formic acid: distilled water, 85:5:10, v/v/v). The gradient elution program was as follows: 0–4 min, 80% A; 4–8 min, linear gradient to 25% A; 8–10 min, held at 25% A; 10–17 min, returned to 80% A; and 17–20 min, re-equilibrated at 80% A. The flow rate was maintained at 1.0 mL/min, and the injection volume was 10 µL.

Chromatograms were monitored at multiple wavelengths according to the maximum absorbance of individual compounds, using the diode array detector: 280 nm for gallic acid, catechin, epicatechin, and epigallocatechin gallate; 320 nm for caffeic acid,

p-coumaric acid, o-coumaric acid, and rosmarinic acid; and 360 nm for flavonols such as quercetin and naringin. Quantification was achieved by external calibration using authentic standards. The selected phenolic and flavonoid standards were chosen based on compounds commonly reported in honey and plant-derived foods in previous studies and their relevance to antioxidant and antimicrobial activities. The identification of phenolic acids and flavonoids was based on comparison of retention times and UV–Vis spectra with those of authentic standards. Calibration curves were constructed using at least five concentration levels within the range of 25–50 $\mu\text{g/mL}$, and linearity was confirmed with coefficients of determination (R^2) greater than 0.99 for all analytes. Method precision was evaluated by repeated injections, and the relative standard deviation (RSD) was less than 5% for all quantified compounds. Measurements were conducted in triplicate for all samples, and results were expressed as mg per 100 g of honey.

2.5 Determination of antioxidant activities and bioactive compound contents

2.5.1 Total phenolic content (TPC)

Total phenolic content was determined using the Folin–Ciocalteu method described by Bertone et al. [18] with slight modifications. For each assay, 1 mL of honey solution (10% w/v in distilled water) was mixed with 2.5 mL of 0.2 N Folin–Ciocalteu reagent, left for 5 min, and then 2 mL of 7.5% Na_2CO_3 was added. The mixture was incubated in the dark at room temperature for 2 h. The absorbance was measured at 760 nm using a UV–Vis spectrophotometer (M509T, Spectronic Camspec Ltd., UK). Calibration was performed with gallic acid (10–100 $\mu\text{g/mL}$). Results were expressed as mg gallic acid equivalents (GAE) per 100 g honey, and all measurements were carried out in triplicate.

2.5.2 Total flavonoid content (TFC)

Total flavonoid content was determined using the aluminum chloride colorimetric method described by Meda et al. (2005) [19] with slight modifications. For the assay, 1 mL of honey solution (50% w/v in distilled water) was mixed with 5 mL of 2% AlCl_3 solution in methanol and incubated at room temperature in the dark for 10 min. The absorbance was then measured at 415 nm using a UV–Vis spectrophotometer. Calibration was performed with catechin (5–40 $\mu\text{g/mL}$). Results were expressed as mg catechin equivalents (CE) per 100 g honey, and all measurements were carried out in triplicate.

2.5.3 Ferric reducing antioxidant power (FRAP) assay

The ferric reducing antioxidant power (FRAP) was determined according to Bolaños de la Torre et al. [20] with minor modifications. FRAP reagent was freshly prepared by mixing 300 mM acetate buffer (pH 3.6), 10 mM 2,4,6-tripyridyl-s-triazine (TPTZ) solution in 40 mM HCl, and 20 mM $\text{FeCl}_3 \cdot 6 \text{H}_2\text{O}$ (10:1:1, v/v/v). For the assay, 0.2 mL of honey solution (50% w/v in distilled water) was mixed with 1.5 mL of FRAP reagent and incubated at 37 °C for 4 min. The absorbance was measured at 593 nm using a UV–Vis spectrophotometer. Calibration was performed using $\text{FeSO}_4 \cdot 7 \text{H}_2\text{O}$ standard solution (300–2,000 $\mu\text{g/mL}$). The results were expressed as $\mu\text{mol Fe}^{2+}$ equivalents per 100 g honey. Each determination was carried out in triplicate.

2.5.4 DPPH radical scavenging activity and ascorbic acid equivalent antioxidant capacity (AEAC)

The antioxidant activity was measured using the DPPH assay according to Meda et al. [19] with slight modifications. For the assay, 0.75 mL of honey solution (30% w/v in distilled water) was mixed with 1.5 mL of 0.1 mM DPPH solution in methanol and incubated in the dark at room temperature for 15 min. The absorbance was measured at 517 nm using a UV–Vis spectrophotometer. Calibration was performed with butylated hydroxytoluene (BHT, 3–50 µg/mL) for DPPH and L-ascorbic acid (3–50 µg/mL) for AEAC. The results were expressed as mg BHT equivalents and mg AAE per 100 g honey. Measurements were conducted in triplicate for all samples.

2.6 Antimicrobial activity (MIC assay)

The antimicrobial activity of honey samples was determined using the broth microdilution method following CLSI [21] and NCCLS [22]. Five bacterial strains, including skin-associated bacteria and representative Gram-positive and Gram-negative species, were tested: *Staphylococcus aureus* (ATCC 25923), *Escherichia coli* (ATCC 25922), *Pseudomonas aeruginosa* (ATCC 27853), *Kocuria rhizophila* (ATCC 9341), and *Bacillus subtilis* (ATCC 6633). Honey samples were dissolved in sterile distilled water and subjected to two-fold serial dilutions in Mueller–Hinton broth using sterile 96-well microplates to obtain final concentrations ranging from 0.06 to 30% (w/v). Bacterial suspensions were prepared from overnight cultures and adjusted to a final concentration of 5×10^5 CFU/mL before being added to each well. Each plate included a growth control (medium with bacterial suspension without honey), a sterility control (medium only), and a sample control (medium with honey without bacteria). Plates were incubated at 37 °C for 18 h under aerobic conditions. The minimum inhibitory concentration (MIC) was defined as the lowest concentration of honey that showed no visible bacterial growth compared with the growth control. All assays were conducted in triplicate.

2.7 Statistical analysis

All statistical analyses were performed using R software (version 4.2.2; R Foundation for Statistical Computing, Vienna, Austria). One-way analysis of variance (ANOVA) was conducted, and significant differences among means were identified using the Least Significant Difference (LSD) test at $p < 0.05$. Pearson correlation analysis was applied to assess relationships among measured parameters. Principal Component Analysis (PCA) was conducted to visualize multivariate relationships and clustering patterns of honey samples. The results are presented as the mean $\pm$ standard deviation (SD) of triplicate determinations.

3 Results and discussion

3.1 Physicochemical properties and sugar compositions

The analysis of basic physicochemical properties of the six honeys (Table 1) revealed significant differences ($p < 0.05$) in their physicochemical composition. Manuka and coffee honeys exhibited the highest total soluble solids (TSS > 80°Brix), whereas Siam weed honey had the lowest (~76°Brix). Fructose content ranged from approximately 34 to 38 g/100 g, while glucose content ranged from 29 to 31 g/100 g across all honeys. Manuka showed the highest values, whereas longan and premium longan honeys

Table 1 Basic chemical composition of Thai honeys from different floral origins

Honey sample	Total soluble solids (°Brix)	Fructose (g/100 g)	Glucose (g/100 g)	pH	Moisture (% wet basis)
Longan	79.57 ± 0.12 ^b	35.57 ± 0.02 ^b	29.81 ± 0.06 ^b	3.49 ± 0.05 ^b	20.90 ± 0.04 ^{ns}
Premium longan (raw honey)	79.53 ± 0.34 ^b	35.75 ± 0.22 ^b	29.35 ± 0.49 ^b	3.43 ± 0.01 ^b	19.95 ± 0.14 ^{ns}
Siam weed	76.30 ± 0.16 ^b	32.48 ± 0.06 ^d	29.01 ± 0.19 ^b	3.75 ± 0.01 ^a	20.66 ± 0.86 ^{ns}
Lychee	79.67 ± 0.12 ^b	34.20 ± 0.52 ^c	29.35 ± 0.17 ^b	3.40 ± 0.05 ^b	20.95 ± 0.59 ^{ns}
Coffee	80.70 ± 0.16 ^a	34.62 ± 0.28 ^{bc}	30.35 ± 0.08 ^a	3.82 ± 0.01 ^a	20.89 ± 0.42 ^{ns}
Manuka	81.23 ± 0.12 ^a	38.11 ± 0.11 ^a	31.07 ± 0.05 ^a	3.36 ± 0.02 ^c	20.50 ± 0.41 ^{ns}

Values are presented as mean ± standard deviation (SD, $n = 3$)

Different superscript letters within the same column indicate significant differences ($p < 0.05$)

“ns” indicates not significantly different ($p > 0.05$)

exhibited comparably high levels. Coffee honey showed intermediate levels. No sucrose or maltose was detected in any of the samples (data not shown), confirming purity and proper maturation. The fructose-to-glucose (F/G) ratio exceeded 1.0 in all honeys, indicating slower crystallization and a prolonged liquid state, which is advantageous for both product quality and marketability.

The pH values varied significantly among samples ($p < 0.05$). Manuka honey was the most acidic (pH 3.36 ± 0.02), followed by premium longan and lychee honeys, whereas coffee and Siam weed honeys exhibited higher pH values (approximately 3.75–3.82), indicating lower acidity but still within the normal acidic range of natural honeys (pH 3.4–4.0). Moisture content across all samples remained within the accepted standard (<21%) and showed no significant differences.

Fundamental parameters such as TSS, glucose and fructose contents, pH, and moisture serve as indicators of honey quality and stability [23]. Manuka and coffee honeys showed relatively higher TSS and sugar contents compared with other samples, consistent with their characteristic sweetness and quality [24]. Honeys with lower pH, such as Manuka and premium longan exhibited stronger acidity, a critical factor for microbial inhibition and product stability [25]. Moisture contents in all samples were within standard limits, ensuring stability and reducing fermentation risk [25].

The absence of sucrose and maltose confirmed honey purity and appropriate harvesting practices [26]. Furthermore, an F/G ratio greater than 1 is advantageous for maintaining liquid form over time [23]. The differences observed between premium longan (raw honey) and conventional longan honeys reflect the influence of processing: raw honey that bypasses heat treatment better preserves quality [9]. These fundamental physicochemical and sugar composition parameters provide a baseline for interpreting subsequent differences in phytochemical composition and biological activities among the studied honeys.

3.2 Quantitative analysis of phenolic and flavonoid compounds

Tables 2 and 3 present the quantitative analysis of phenolic and flavonoid compounds in six types of honey. Five major phenolic acids were identified: gallic acid, caffeic acid, p-coumaric acid, o-coumaric acid, and rosmarinic acid, with significant variations among honey types ($p < 0.05$) (Table 2). Manuka and premium longan honeys (raw honey) exhibited the highest levels of quantified phenolic compounds, dominated by gallic acid and caffeic acid. Coffee and conventional longan honeys showed moderate total phenolic levels, though they were still relatively rich in gallic acid and caffeic acid.

Table 2 Phenolic compound composition of Thai honeys from different floral origins

Honey Sample	Phenolic compound composition (mg/100 g)					
	Gallic acid	Caffeic acid	<i>p</i> -coumaric acid	<i>o</i> -coumaric acid	Rosmarinic acid	Sum of phenolic compounds
Longan	1.70 ± 0.08 ^b	0.22 ± 0.03 ^b	0.16 ± 0.02 ^a	0.09 ± 0.09 ^b	0.04 ± 0.01 ^b	2.22
Premium longan (raw honey)	1.80 ± 0.04 ^{ab}	0.21 ± 0.02 ^b	0.17 ± 0.01 ^a	0.11 ± 0.01 ^a	0.05 ± 0.04 ^b	2.32
Siam weed	0.75 ± 0.01 ^c	0.18 ± 0.01 ^c	0.12 ± 0.03 ^b	0.09 ± 0.04 ^b	LOD	1.14
Lychee	1.69 ± 0.01 ^b	0.24 ± 0.02 ^b	0.17 ± 0.05 ^a	LOD	0.08 ± 0.04 ^a	2.17
Coffee	1.77 ± 0.02 ^b	0.23 ± 0.01 ^b	0.15 ± 0.05 ^a	LOD	0.05 ± 0.01 ^b	2.20
Manuka	1.98 ± 0.09 ^a	0.27 ± 0.01 ^a	0.17 ± 0.01 ^a	0.09 ± 0.06 ^b	LOD	2.60

Values are presented as mean ± standard deviation (SD, *n* = 3)

Different superscript letters within the same column indicate significant differences (*p* < 0.05)

“LOD” indicates concentrations below the limit of detection of the analytical method

Table 3 Flavonoid compound composition of Thai honeys from different floral origins

Honey Sample	Flavonoid compound composition (mg/100 g)					Sum of flavonoid compounds
	Catechin	Quercetin	Epigallocatechin gallate	Epicatechin	Naringin	
Longan	3.59 ± 0.08 ^d	0.19 ± 0.0 ^a	0.38 ± 0.01 ^a	0.07 ± 0.01 ^b	0.10 ± 0.01 ^c	4.33
Premium longan (raw honey)	6.31 ± 0.03 ^b	0.18 ± 0.0 ^{ab}	0.37 ± 0.00 ^b	0.06 ± 0.01 ^b	0.13 ± 0.02 ^{bc}	7.05
Siam weed	0.93 ± 0.01 ^e	0.11 ± 0.0 ^b	0.39 ± 0.01 ^b	0.09 ± 0.01 ^b	0.12 ± 0.01 ^{bc}	1.64
Lychee	3.11 ± 0.05 ^{de}	0.19 ± 0.0 ^{ab}	0.24 ± 0.00 ^c	0.40 ± 0.0 ^a	0.46 ± 0.01 ^a	4.39
Coffee	4.15 ± 0.04 ^c	0.18 ± 0.0 ^{ab}	0.39 ± 0.01 ^b	LOD	0.09 ± 0.01 ^c	4.86
Manuka	7.81 ± 0.0 ^a	0.21 ± 0.0 ^a	0.44 ± 0.01 ^b	0.09 ± 0.0 ^b	0.16 ± 0.00 ^b	8.72

Values are presented as mean ± standard deviation (SD, *n* = 3)

Different superscript letters within the same column indicate significant differences (*p* < 0.05)

“LOD” indicates concentrations below the limit of detection of the analytical method

Lychee honey contained higher levels of caffeic acid and rosmarinic acid compared to other types, whereas *p*-coumaric acid was detected among all the selected honeys at comparable levels. In contrast, *o*-coumaric acid and rosmarinic acid were only detected in certain samples. Siam weed honey contained the lowest phenolic levels, consistent with its weak antioxidant potential, emphasizing the role of gallic acid and caffeic acid in honey bioactivity.

For flavonoids, five compounds were detected: catechin, quercetin, epigallocatechin gallate, epicatechin, and naringin, showing significant differences in type and concentration among samples (*p* < 0.05) (Table 3). Manuka and premium longan honeys exhibited the highest total flavonoid levels, with catechin as the dominant constituent. Coffee and lychee honeys showed moderate levels, with lychee honey being particularly rich in epicatechin and naringin, which may contribute to its distinct antioxidant activity. Catechin was especially abundant in Manuka and premium longan honeys, consistent with their strong antioxidant capacities. In contrast, Siam weed honey exhibited the lowest diversity and concentration of flavonoids. Quercetin and epigallocatechin gallate were present at relatively comparable levels among several honeys, except for Siam weed honey, which contained the lowest quercetin levels, and coffee honey, which lacked epicatechin.

Overall, the floral origin and production process influenced the flavonoid composition and bioactivity of honey. Honeys rich in catechin, epicatechin, and quercetin generally exhibited stronger biological activities. These variations in phenolic and flavonoid

profiles can be attributed to differences in the botanical sources of nectar. Manuka honey, derived from *Leptospermum scoparium*, is well recognized for its richness in phenolic acids and flavonoids with strong redox properties, which explains its high contents of gallic acid, catechin, and quercetin [3, 7]. Similarly, longan honey (*Dimocarpus longan* Lour.) has been reported to contain abundant flavonoids and phenolic acids associated with antioxidant activity, consistent with the profiles observed in premium longan honey [6, 9].

Coffee honey reflects the phenolic composition of *Coffea* species, which are known sources of caffeic and chlorogenic acids, contributing to its moderate antioxidant capacity [4, 27]. Lychee honey (*Litchi chinensis* Sonn.) is associated with flavonoids such as epicatechin and naringin, which have been reported as characteristic secondary metabolites of lychee-derived products [28]. In contrast, Siam weed honey exhibited limited phenolic and flavonoid diversity, consistent with the phytochemical profile of *Chromolaena odorata* and its comparatively lower bioactivity [29].

Quantitative profiling revealed that honeys from six floral origins varied in phenolic and flavonoid composition. Gallic acid was the predominant constituent in many samples, particularly premium longan (raw honey) and Manuka, and plays a critical role in antioxidant activity [3]. Caffeic acid and p-coumaric acid, detected at moderate levels, also exhibit antioxidant and anti-inflammatory properties and are associated with higher TPC values [4, 13]. The main mechanism of these phenolic acids is attributed to their multiple hydroxyl groups, which readily donate electrons to neutralize free radicals, thereby stabilizing reactive species and preventing oxidative chain reactions [3].

Among flavonoids, catechin and quercetin were abundant in Manuka, premium longan, and lychee honeys and are well known for their antioxidant, anti-inflammatory, and immunomodulatory properties [6, 30]. Quercetin has also been reported to provide photoprotective effects and support collagen synthesis [27], whereas epicatechin and naringin, particularly abundant in lychee honey, are associated with skin-related bioactivities [28].

Comparison among honey types indicated that Manuka and premium longan honeys (raw honey) contained the most diverse and concentrated phenolic and flavonoid compounds, particularly gallic acid, caffeic acid, quercetin, and catechin. These compositional characteristics reflect the strong contribution of phenolic and flavonoid constituents to honey bioactivity [12]. Coffee honey was characterized by relatively high levels of caffeic acid and catechin, whereas lychee honey exhibited higher proportions of quercetin and naringin despite moderate total phenolic content. Conventional longan honey showed a composition similar to raw honey but with lower concentrations of key compounds, likely influenced by processing factors such as heating and shorter harvest duration [9]. Siam weed honey consistently exhibited the lowest diversity and abundance of phenolic and flavonoid compounds, consistent with its distinct botanical origin.

The quantitative profiling clearly demonstrates that the phenolic and flavonoid composition of honey is strongly dependent on floral origin and botanical source. Differences in the abundance of key phenolic acids (e.g., gallic and caffeic acids) and flavonoids (e.g., catechin, quercetin, epicatechin, and naringin) reflect the distinct secondary metabolite profiles of nectar-producing plants. These compositional variations provide a chemical basis for the differences in antioxidant performance discussed in Sect. 3.3 and

the antimicrobial activities evaluated in Sect. 3.4, highlighting the central role of plant-derived phytochemicals in determining honey bioactivity.

3.3 Antioxidant activities and bioactive compound contents

Six types of honey—longan, premium longan (raw honey), Siam weed, lychee, coffee, and Manuka—were analyzed for antioxidant activity using the ferric reducing antioxidant power (FRAP), DPPH radical scavenging activity, and ascorbic acid equivalent antioxidant capacity (AEAC) assays. Bioactive compound contents, including total phenolic content (TPC) and total flavonoid content (TFC), were also determined (Table 4).

Manuka honey exhibited the highest values across all parameters, including FRAP, DPPH, AEAC, TPC, and TFC, with statistically significant differences ($p < 0.05$). These findings are consistent with Deng et al. [28], who reported that Manuka honey contains polyphenols such as p-hydroxybenzoic acid and chlorogenic acid, contributing to its strong antioxidant properties.

The superior antioxidant activity and higher bioactive compound contents observed in Manuka honey can be largely attributed to differences in floral origin and plant secondary metabolite composition. Manuka honey is predominantly derived from *Leptospermum scoparium*, a plant known to be rich in phenolic acids and flavonoids with strong redox potential. Variations in nectar and pollen composition among plant species directly influence the types and concentrations of phytochemicals collected by bees, resulting in distinct chemical profiles and biological activities of honey. Previous studies have demonstrated that floral origin is a primary determinant of honey antioxidant capacity through its impact on phenolic and flavonoid composition [3].

Premium longan honey (raw honey) ranked second, showing significantly higher values across all parameters than conventional longan honey. This difference can be attributed to the absence of heat treatment during production, which preserves thermolabile compounds such as polyphenols, flavonoids, glucose oxidase, vitamin C, and organic acids [9, 31]. Conventional longan honey is typically harvested early (approximately 7 days), resulting in high moisture content and the need for heat treatment (50–65 °C) prior to packaging, whereas raw honey is harvested after a longer maturation period (18–21 days), allowing gradual moisture reduction without heating. Consequently, premium longan honey demonstrated antioxidant bioactivities approaching those of Manuka honey.

Table 4 Antioxidant activities and bioactive compound contents of Thai honeys from different floral origins

Honey sample	FRAP value ($\mu\text{mol Fe}^{2+}/100\text{ g}$)	DPPH scavenging activity (mg BHT eq./100 g)	AEAC (mg AAE/100 g)	Total phenolic content (mg GAE/100 g)	Total flavonoid content (mg CE/100 g)
Longan	538.73 $\pm$ 2.15 ^e	17.39 $\pm$ 1.11 ^c	12.59 $\pm$ 0.74 ^c	53.58 $\pm$ 2.89 ^c	32.45 $\pm$ 1.08 ^b
Premium longan (raw honey)	849.28 $\pm$ 0.65 ^b	27.06 $\pm$ 0.12 ^b	20.54 $\pm$ 0.10 ^b	65.23 $\pm$ 2.08 ^b	40.86 $\pm$ 0.43 ^a
Siam weed	224.58 $\pm$ 0.49 ^f	9.46 $\pm$ 0.45 ^d	6.07 $\pm$ 0.66 ^d	32.36 $\pm$ 2.78 ^d	11.52 $\pm$ 1.56 ^c
Lychee	575.90 $\pm$ 1.52 ^d	16.61 $\pm$ 0.96 ^c	11.94 $\pm$ 1.20 ^c	53.85 $\pm$ 2.36 ^c	37.81 $\pm$ 0.48 ^b
Coffee	662.23 $\pm$ 0.42 ^c	18.16 $\pm$ 0.75 ^c	13.22 $\pm$ 1.09 ^c	50.73 $\pm$ 1.69 ^c	37.22 $\pm$ 0.65 ^b
Manuka	991.97 $\pm$ 1.57 ^a	30.72 $\pm$ 1.52 ^a	23.56 $\pm$ 0.89 ^a	68.02 $\pm$ 2.77 ^a	45.35 $\pm$ 1.28 ^a

Values are presented as mean $\pm$ standard deviation (SD, $n = 3$)

Different superscript letters within the same column indicate significant differences ($p < 0.05$)

Among processed honeys, coffee honey exhibited strong antioxidant potential, characterized by comparatively high total flavonoid content (TFC) and higher FRAP and AEAC values than those of conventional longan and Siam weed honeys. This observation corresponds with the presence of caffeic acid and chlorogenic acid identified in quantitative profiling [6, 27]. Longan and lychee honeys showed comparable antioxidant activities with similar total phenolic content (TPC) levels; however, lychee honey exhibited slightly higher TFC, which may reflect structural differences in its predominant flavonoids. In contrast, Siam weed honey consistently exhibited the lowest antioxidant capacity across all parameters, consistent with its minimal phenolic and flavonoid contents, suggesting that floral origin may limit the diversity of bioactive constituents.

Based on antioxidant capacity, the honeys could be categorized into three groups: high potential (Manuka and premium longan), moderate potential (coffee, lychee, and conventional longan), and low potential (Siam weed). These results highlight the influence of floral origin and processing conditions on honey bioactivities. In particular, variations in polyphenol and flavonoid concentrations are directly associated with antioxidant capacity and are likely to influence antimicrobial properties. This observation further supports the close relationship between total phenolic and flavonoid contents (TPC and TFC) and antioxidant activity, which is strongly governed by differences in floral origin.

The antioxidant activity of honey is closely associated with its total phenolic and flavonoid contents, which act as major contributors to redox-related bioactivities [27]. Pearson's correlation matrix (Fig. 1) further demonstrated strong positive correlations between TPC and TFC with FRAP, DPPH, and AEAC, with TPC showing $r > 0.90$ with all parameters. These findings align with Chua et al. (2013) [6], who suggested that TPC and TFC can serve as reliable indicators of honey's antioxidant activity. Other supportive constituents, such as vitamins and enzymes (e.g., glucose oxidase), may act synergistically [32], contributing to complex bioactivities that cannot be explained by individual compounds alone.

The results confirm that Thai premium longan honey (raw honey) exhibits antioxidant potential comparable to that of Manuka. TPC and TFC may therefore serve as reliable indicators of honey's bioactive quality, highlighting its potential as a high-value raw material. Collectively, these findings suggest that premium longan honey could serve as a valuable alternative to Manuka in functional food and cosmetic applications.

3.4 Antimicrobial activity

This study evaluated the antimicrobial activity of six floral honeys against five bacteria relevant to skin health and commonly used as reference strains in antimicrobial evaluation: *Staphylococcus aureus*, a major pathogen in acne vulgaris and skin infections such as folliculitis and abscesses [33]; *Pseudomonas aeruginosa*, commonly isolated from infected, burn, and chronic wounds, which forms biofilms and secretes tissue-damaging toxins [34]; *Escherichia coli*, which may contaminate open wounds and trigger inflammation in chronic ulcers [35]; *Kocuria rhizophila*, a commensal skin bacterium that contributes to microbiome balance [36]; and *Bacillus subtilis*, known to suppress pathogens and promote skin immunity [37]. These microorganisms are key targets in skin-care applications aiming to reduce inflammation, control infection, and support microbial homeostasis.

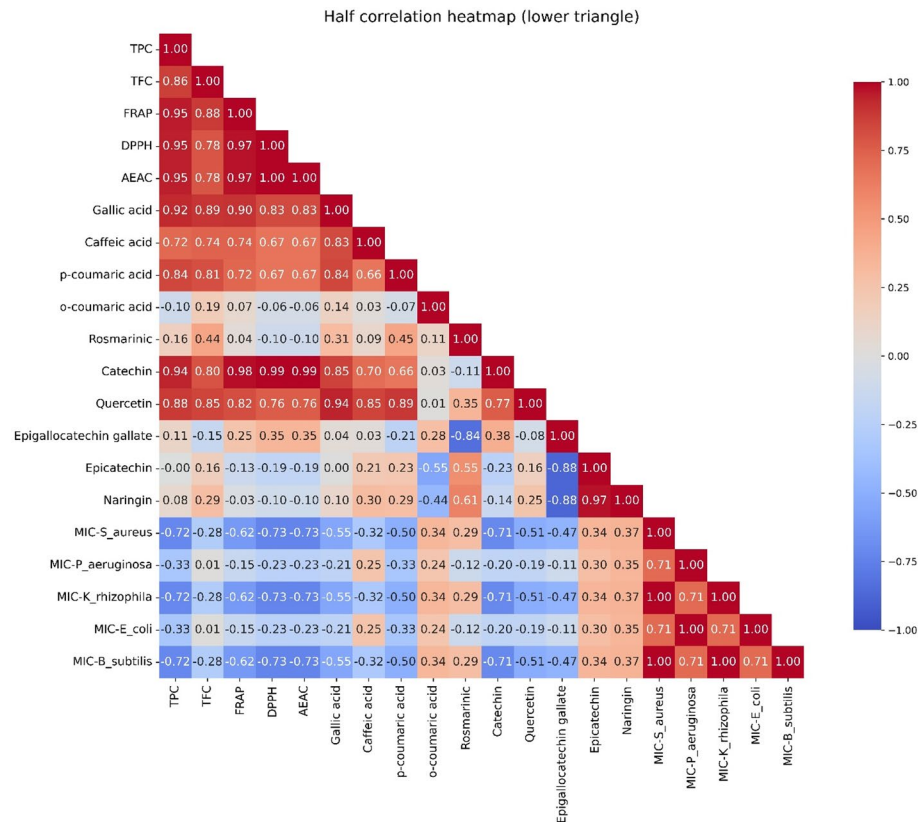


Fig. 1 Pearson's correlation matrix heatmap showing the relationships among antioxidant activities (FRAP, DPPH, AEAC), total phenolic content (TPC), total flavonoid content (TFC), quantified phenolic acids (e.g., gallic, caffeic, and p-coumaric acids), quantified flavonoids (e.g., catechin, quercetin, and epigallocatechin gallate), and MIC values against five bacterial strains (*Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Kocuria rhizophila*, *Escherichia coli*, and *Bacillus subtilis*). Positive correlations are indicated in red, while negative correlations are indicated in blue. The heatmap illustrates potential mechanistic associations between phenolic/flavonoid composition, antioxidant capacity, and antibacterial efficacy of the tested honeys

Table 5 Minimum inhibitory concentration (MIC) of Thai honeys from different floral origins against skin-associated bacteria (% w/v)

Honey Sample	<i>Staphylococcus aureus</i>	<i>Pseudomonas aeruginosa</i>	<i>Kocuria rhizophila</i>	<i>Escherichia coli</i>	<i>Bacillus subtilis</i>
Longan	15 ± 0.00 ^b	30 ± 0.00 ^a	15 ± 0.00 ^b	15 ± 0.00 ^b	15 ± 0.00 ^b
Premium longan (raw honey)	7.5 ± 0.00 ^c	15 ± 0.00 ^b	15 ± 0.00 ^b	15 ± 0.00 ^b	15 ± 0.00 ^b
Siam weed	30 ± 0.00 ^a	30 ± 0.00 ^a	30 ± 0.00 ^a	30 ± 0.00 ^a	30 ± 0.00 ^a
Lychee	30 ± 0.00 ^a	30 ± 0.00 ^a	30 ± 0.00 ^a	30 ± 0.00 ^a	30 ± 0.00 ^a
Coffee	30 ± 0.00 ^a	30 ± 0.00 ^a	30 ± 0.00 ^a	30 ± 0.00 ^a	30 ± 0.00 ^a
Manuka	7.5 ± 0.00 ^c	30 ± 0.00 ^a	15 ± 0.00 ^b	30 ± 0.00 ^a	15 ± 0.00 ^b

Values are presented as mean ± standard deviation (SD, *n* = 3)

Different superscript letters within the same column indicate significant differences (*p* < 0.05)

MIC (minimum inhibitory concentration) represents the lowest concentration of honey that inhibited visible microbial growth, expressed as % (w/v)

As shown in Table 5, premium longan honey (raw honey) exhibited the lowest MIC values, inhibiting *S. aureus* at 7.5% (w/v) and suppressing both Gram-positive bacteria (*S. aureus*, *K. rhizophila*, *B. subtilis*) and Gram-negative bacteria (*P. aeruginosa*, *E. coli*) at concentrations ≤ 15.0% (w/v). Manuka honey displayed comparable efficacy against Gram-positive bacteria but was less effective against Gram-negative strains, requiring

concentrations up to 30.0% (w/v) for inhibition. Conventional longan honey showed MIC values of 15.0% (w/v) against most bacteria, increasing to 30.0% (w/v) for *P. aeruginosa*. Although less potent than raw honey, its activity remained within the effective antimicrobial range and was comparable to Manuka honey, particularly against Gram-positive bacteria. In contrast, coffee, lychee, and Siam weed honeys consistently exhibited the weakest antimicrobial potential, with MIC values of 30.0% (w/v) across all tested bacteria, indicating significantly lower efficacy compared with high-bioactivity honeys.

Gram-positive bacteria generally responded more sensitively to honey, particularly to high-bioactivity types such as premium longan (raw honey) and Manuka, which inhibited growth at $\leq 15\%$ (w/v), whereas Gram-negative bacteria required higher concentrations for inhibition. This differential susceptibility can be attributed to fundamental differences in bacterial cell wall structure. The absence of an outer membrane in Gram-positive bacteria facilitates the penetration of phenolic acids, flavonoids, hydrogen peroxide, and methylglyoxal, enabling more effective disruption of cellular functions. In contrast, the lipopolysaccharide-rich outer membrane of Gram-negative bacteria restricts the diffusion of these antimicrobial compounds, contributing to increased resistance to honey-derived bioactive components [7, 8, 11].

Phenolic and flavonoid profiling supported these findings, as reflected by the MIC patterns shown in Table 5, where honeys rich in gallic acid, caffeic acid, and catechin (e.g., premium longan raw honey and Manuka) exhibited stronger antimicrobial activities [3, 7]. These compounds disrupt microbial membranes and inhibit specific enzymes [4]. Commensal bacteria such as *K. rhizophila* and *B. subtilis* were also sensitive to high-bioactivity honeys, similar to pathogens, suggesting potential applications for targeted modulation of the skin microbiome [36, 37].

The antimicrobial mechanisms of honey are multifactorial and broadly categorized as peroxide-based and non-peroxide-based. The peroxide-based effect involves hydrogen peroxide (H_2O_2) generated by glucose oxidase secreted by bees during honey production, although this enzyme is heat- and light-sensitive [8]. Consequently, raw honeys that bypass heating retain stronger antimicrobial activity than processed honeys [9]. By contrast, Manuka honey is distinguished by non-peroxide-based mechanisms, relying on specific compounds such as methylglyoxal (MGO), defensin-1, phenolic acids, and flavonoids, which effectively inhibit both pathogenic and drug-resistant bacteria even in the absence of H_2O_2 [7, 11].

In addition to chemical mechanisms, honey exerts physical effects through its high sugar concentration ($> 80\%$), creating osmotic pressure that dehydrates microbial cells; its acidic pH (3.2–4.5); and low water activity (0.56–0.62), which together create unfavorable conditions for bacterial growth [38]. Honeys with higher levels of gallic acid, catechin, and caffeic acid also showed synergistic effects, disrupting cell walls and inducing oxidative stress [39].

Although premium longan and conventional longan honeys shared similar MIC values against certain Gram-positive strains, particularly *S. aureus*, *K. rhizophila*, and *B. subtilis*, raw honey exhibited superior bioactivity overall. This reflects its higher antioxidant levels and enriched bioactive compounds, which were preserved by extended in-hive maturation and the absence of heat treatment [9, 31]. Premium longan honey (raw honey) demonstrated antimicrobial activity comparable to Manuka honey, supported by low MIC values and high bioactive compound content, particularly polyphenols

involved in antimicrobial mechanisms. These findings support the potential of Thai raw honey as a reliable local alternative to Manuka honey for the development of skincare products targeting antimicrobial and anti-inflammatory functions.

3.5 Pearson correlation matrix analysis: correlation between bioactive compounds and biological activities

The Pearson correlation matrix (Fig. 1) provided complementary insight into the relationships between phenolic and flavonoid compounds and the biological activities of honey. Several significant positive and negative correlations were observed.

Gallic acid exhibited a strong positive correlation with FRAP ($r = 0.90$, $p < 0.01$) and total phenolic content (TPC), highlighting its role as a major antioxidant compound. This observation aligns with the results reported by Cianciosi et al. (2018) [3]. Catechin exhibited a strong correlation with total flavonoid content (TFC) ($r \approx 0.80$), reflecting its contribution as a potent antioxidant flavanol, particularly abundant in Manuka and coffee honeys [6]. Quercetin was also highly correlated with both TFC ($r = 0.85$) and AEAC ($r = 0.76$), confirming its significance as a flavonol with antioxidant capacity [6].

TPC displayed a moderate negative correlation with the MIC against *Staphylococcus aureus* ($r = -0.65$), reinforcing its potential antimicrobial activity. This finding aligns with Tananaki et al. (2024) [14]. By contrast, basic physicochemical parameters such as pH, moisture, glucose, and fructose showed no clear correlations with the biological activities examined.

Taken together, the Pearson correlation matrix and PCA highlighted the pivotal roles of phenolic and flavonoid compounds as primary drivers of antioxidant and antimicrobial activities. These compounds may serve as biomarker candidates for identifying honey varieties with superior bioactive potential, facilitating their application in functional food and cosmeceutical development.

Among the honeys tested, Manuka and premium longan (raw honey) displayed distinctive bioactive profiles, positioning them as high-potential candidates for product innovation. Notably, premium longan honey, as a Thai local product, should be further promoted for commercial utilization to enhance community-level economic value.

3.6 Multivariate analysis: PCA interpretation of bioactive and antimicrobial profiles of honeys

Principal component analysis (PCA) was applied to describe the relationships among quantitative phenolic and flavonoid compounds, total phenolic content (TPC), total flavonoid content (TFC), antioxidant activities (FRAP, DPPH, AEAC), and antimicrobial activity (MIC) in honeys derived from different floral origins.

The PCA (Fig. 2) revealed that PC1 (Dim1) and PC2 (Dim2) together explained 75.1% of the total variance (52.4% and 22.7%, respectively), sufficient to distinguish the biochemical differences among honeys from various floral origins. PC1 showed strong positive correlations with TPC, TFC, antioxidant activities (FRAP, DPPH, AEAC), and major phenolic/flavonoid compounds, including gallic acid, catechin, and quercetin. PC2, on the other hand, was associated with antimicrobial activity (MIC) against bacterial strains relevant to skin health and commonly used in antimicrobial studies, including *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Kocuria rhizophila*, *Escherichia coli*, and *Bacillus subtilis*.

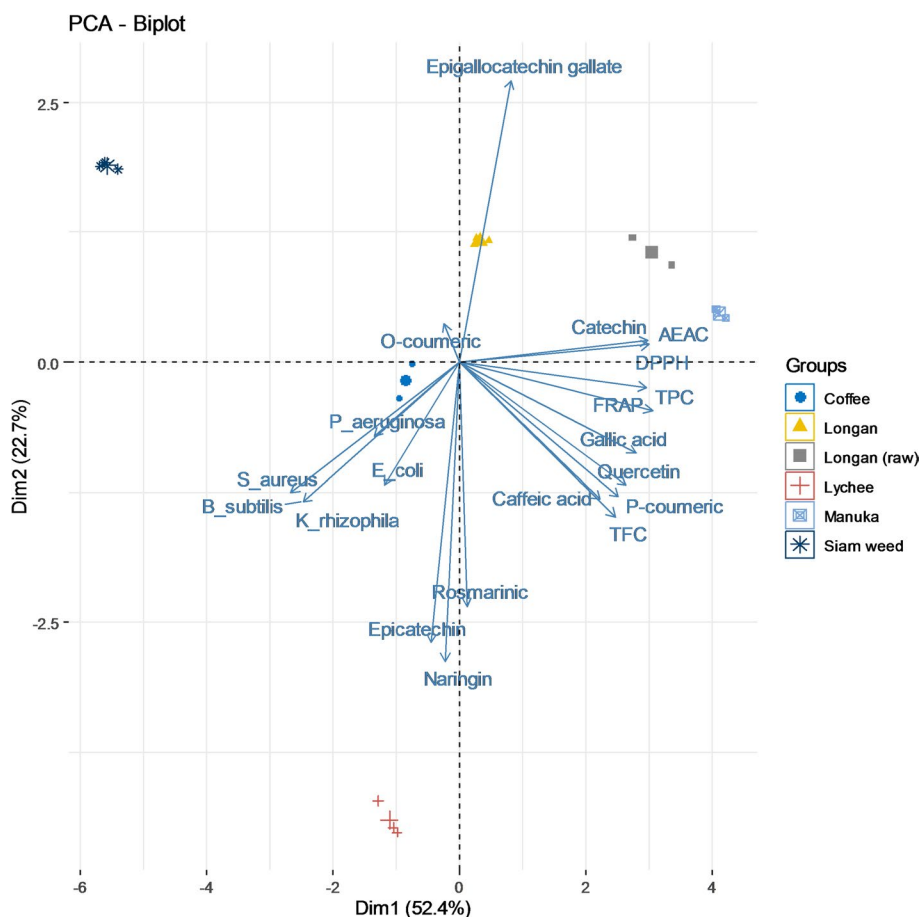


Fig. 2 Principal component analysis (PCA) biplot illustrating the distribution of honey samples from different floral origins. Symbols represent individual honey types, while vectors represent bioactive compounds and biological variables, including antioxidant activities (FRAP, DPPH, AEAC), total phenolic content (TPC), total flavonoid content (TFC), representative phenolic acids (e.g., gallic, caffeic, p-coumaric, o-coumaric, and rosmarinic acids), flavonoids (e.g., catechin, quercetin, epigallocatechin gallate, epicatechin, and naringin), and minimum inhibitory concentration (MIC) values against five bacterial strains (*Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Kocuria rhizophila*, *Escherichia coli*, and *Bacillus subtilis*). MIC variables were positioned opposite to antioxidant and phenolic vectors, reflecting their negative correlations

The PCA biplot (Fig. 2) grouped honeys according to their bioactivities into three major clusters. The high-potential cluster (Cluster 1) included Manuka and premium longan (raw honey), with high antioxidant and bioactive variables such as catechin, AEAC, DPPH, FRAP, and TPC. These two honeys exhibited the highest phenolic and flavonoid contents, as well as pronounced antioxidant and antimicrobial properties, particularly the lowest MIC against *S. aureus* (7.5% w/v). The moderate-potential cluster (Cluster 2) consisted of lychee, coffee, and conventional longan honeys.

Lychee honey, positioned in the lower region of the plot, contained naringin, epicatechin, and rosmarinic acid. Despite its high TFC, it exhibited limited antimicrobial activity. Coffee honey, located in the upper left quadrant, was associated with caffeic acid and demonstrated moderate antioxidant activity together with selective antimicrobial effects.

Conventional longan honey was positioned with epigallocatechin gallate and o-coumaric acid, showing moderate bioactivity but significantly lower than premium longan honey. Finally, the low-potential cluster (Cluster 3) comprised Siam weed honey, which

was distinctly separated from all major bioactive variables, reflecting its lowest bioactivities among the tested honeys. Comparisons between premium and conventional longan honeys emphasized that, despite sharing the same floral origin, raw honey preserved higher levels of bioactive compounds and functional activities owing to extended in-hive maturation and absence of heat treatment.

The loading plot indicated that gallic acid, catechin, quercetin, and caffeic acid were the most influential contributors to honey classification, showing strong associations with TPC, TFC, and antioxidant indices (FRAP, DPPH, AEAC). In contrast, MIC values were negatively correlated with gallic acid and catechin, indicating that higher concentrations of these compounds corresponded to stronger antimicrobial activities (lower MIC). These results point out the critical function of specific phenolic and flavonoid compounds in driving the functional bioactivities of honey.

3.7 Limitations and future directions

Despite the comprehensive evaluation of phenolic–flavonoid composition, antioxidant capacity, and antimicrobial activity of Thai monofloral honeys, several limitations should be acknowledged. First, honey samples were collected during a single harvesting period; therefore, seasonal variations in floral availability and environmental conditions were not addressed. Second, quantitative analysis focused on selected phenolic acids and flavonoids, and thus other minor or unidentified bioactive compounds may also contribute to the observed biological activities. In addition, antimicrobial activity was assessed using *in vitro* MIC assays, which may not fully reflect efficacy in complex biological systems or final product formulations.

Future studies should expand sample collection across different harvesting seasons and geographic regions to better capture natural variability. The application of untargeted metabolomics approaches could provide a more comprehensive understanding of honey phytochemical profiles. Moreover, mechanistic investigations into membrane disruption, biofilm inhibition, and synergistic interactions between phenolic compounds and physicochemical factors are warranted. Finally, translational studies evaluating the stability and bioactivity of honey-derived ingredients in functional food and cosmeceutical formulations would further support the practical utilization of Thai monofloral honeys, particularly premium longan honey, as high-value bioresources.

4 Conclusion

This study compared six Thai honeys against Manuka, the premium honey. Manuka and premium longan (raw) honeys showed the highest potential and were enriched with phenolic and flavonoid compounds such as gallic acid, caffeic acid, quercetin, and catechin. These compounds were strongly associated with antioxidant and antimicrobial properties. Premium longan honey outperformed conventional longan. Its natural in-hive maturation, without heat treatment, preserved thermosensitive compounds and maintained bioactivities comparable to Manuka. Lychee honey contained high flavonoids but showed limited antimicrobial effects, while coffee and conventional longan honeys displayed moderate activities. In contrast, Siam weed honey consistently exhibited the lowest bioactive contents and functional properties. Multivariate analyses confirmed the functional clustering of honeys and identified key compounds driving bioactivity. Collectively, the findings highlight premium longan honey as a high-value local alternative

to Manuka for functional food and cosmeceutical development. Future work should validate these findings in vivo and advance prototype products to fully exploit their bioactive potential.

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Author contributions

WS was solely responsible for the study conception and design, sample preparation, experimental work, data acquisition, data analysis, interpretation of results, and manuscript writing. WS approved the final version of the manuscript.

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Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study did not involve human participants or animals. Therefore, ethical approval was not required.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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