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Review

A Comprehensive Review of Stingless Bee Products: Phytochemical Composition and Beneficial Properties of Honey, Propolis, and Pollen

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Abstract: The stingless bee has been gaining more attention in recent years due to the uniqueness and benefits of its products. Similar to the common honeybee, stingless bees also produce honey, propolis, and pollen, which offer superior benefits for direct or indirect consumption. However, reports on the benefits of stingless bee products are scarce. This article summarises recent reports on stingless bee products. The function and application of the properties of the products such as phenolic compounds, antioxidant properties, and chemical content are elucidated. The antimicrobial properties and anticancer potential of the products are also highlighted. Future trends, potential, and uniqueness of stingless bee products are discussed. Stingless bee honey is highlighted as a superfood that exceptionally has the potential to be an active ingredient in treating cancer. Stingless bee propolis has been extensively studied for its rich beneficial chemical compounds that contribute to its antioxidant properties. Though studies on stingless bee pollen are scarce, it has been reported that it also has the potential of being a functional food.

Keywords: stingless bee honey; stingless bee propolis; stingless bee pollen; antioxidant; antimicrobial; anticancer

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1. Introduction

European honeybees and stingless bees are the two most common bees amid other bees managed for honey. The European honeybee is grouped into the *Apis* genus, whereas the stingless bees may be classified into two genera, which are *Melipona* and *Trigona* [1]. A tribe of stingless bees—*Meliponini*, known as *Kelulut* in the Malay language—have been estimated to include approximately 500 species that may be found in the tropical and subtropical areas around the globe, of which 68 species have been identified in Malaysia alone [2]. Recently, the production of stingless bee honey has been growing, particularly in Southeast Asia. The growing production of stingless bee honey has brought stingless bee products into the limelight [3]. Some of the stingless bee species that are commercially bred by farmers are *Geniotrigona thoracica* (Smith, 1857), *Heterotrigona itama* (Cockerell, 1918), *Lepidotrigona terminata* (Smith, 1878), and *Tetragonula laeviceps* (Smith, 1857) [4]. The selling price of stingless bee honey (*Trigona* species) is about USD 100 per kilogram, which attracts progressive commercial development in Malaysia, the Philippines, and India [5]. Stingless bee honey also has been recognised as a superfood due to its highly nutritional and therapeutic properties [6].

Stingless bees have non-aggressive behaviour, due to which the colony can be manipulated easily through an artificial hive compared to common honey bees, which are more susceptible to diseases and often abandon their hives [7]. Stingless bees also play a significant role in the ecosystem. The bees may tolerate seasonal changes and extreme environmental conditions. The activity of stingless bee farming could encourage bee conservation, as the natural environment of bees is decreasing due to human activities [8]. Despite modifying floral nectar chemically and storing it as honey, which is popularly known for its distinct flavour and aroma, fluid texture, and slow crystallisation, stingless bees are outstanding pollinators in tropical and subtropical ecosystems [9]. An artificial hive (Figure 1) such as a Mustafa-Hive has been proven to be a good system in stingless bee farming. The Mustafa-Hive benefits stingless bees and farmers, as it encourages colony expansion, hygienic harvesting, disease prevention, and protection from predators [10].

Figure 1. Mustafa-Hive system used by Malaysian farmers. Reprinted with permission from Ref. [10]. 2018, Penerbit Universiti Sains Malaysia.

Similar to European honeybees, stingless bees also produce honey, propolis, and bee pollen [7]. Thus, in this review, stingless bee products, properties, benefits, and potential applications are discussed. A comprehensive review and recent updates concerning the health benefits of stingless bee products, which include antioxidant, antimicrobial, and anticancer properties, are highlighted. This paper also highlights the importance of increasing research investment into stingless bee products to encourage their production and use.

2. Stingless Bee Honey

Stingless bees are a highly eusocial insect, and similar to European honeybees, stingless bees produce and store honey in their hives. However, the amount of honey stored in the hive of a stingless bee is less than that of European honeybees [11]. Honey stored by stingless bees is fivefold less than that of European honeybees, with the average production per colony of stingless bee honey only up to 1 kg, compared to European honeybee honey, which can be up to 5 kg per colony [12].

In general, the quality parameters used to evaluate stingless bee honey include moisture content, pH, free acidity, organic acids, and 5-hydroxymethylfurfural [13]. Unlike European honeybee honey, which has International Honey Commission (IHC) standards to monitor the honey quality [14], the international standard for quality control of stingless bee honey has not yet been established. Vit et al. [15] proposed that stingless bee honey quality should have a moisture content maximum value of 30 g/100 g, sum of fructose and glucose minimum value of 50 g/100 g, sucrose content maximum value of 6 g/100 g, free acidity maximum value of 85 meq/kg, ash content maximum value of

0.5 g/100 g, hydroxymethylfurfural (HMF) content maximum value of 40 mg/kg, and diastase activity minimum value of 3 diastase number (DN). Recently, the Department of Malaysian Standards [16] published quality standards for Malaysian stingless bee honey to control the supply and sale of stingless bee honey in Malaysia. The department stated that good-quality stingless bee honey should have a moisture content with a maximum value of 35 g/100 g, sum of fructose and glucose maximum value of 85 g/100 g, sucrose content maximum value of 7.5 g/100 g, maltose content maximum value of 9.5 g/100 g, ash content maximum value of 1.0 g/100 g, HMF content maximum value of 30 mg/kg, pH value within 2.5 and 3.8, and natural phenolic compounds to be present without any value limit. Though IHC Standards were not meant for stingless bee honey, a comparison of the proposed standards by Vit et al. [15] and the Malaysian Standards for stingless bee honey is shown in Table 1.

Table 1. Comparison of European honeybee honey standards with stingless bee honey standards.

Parameter	Standards		
	International Honey Commission (European Honeybee Honey)	Vit et al. [15] (Stingless Bee Honey)	Department of Malaysian Standards (Stingless Bee Honey)
Moisture (g/100 g)	≤20	≤30	≤35
Sum of fructose and glucose (g/100 g)	≥60	≥50	≥85
Sucrose (g/100 g)	≤5	≤6	≤7.5
Maltose (g/100 g)	-	-	≤9.5
Free acidity (meq/100 g)	≤50	≤85	-
Ash content (g/100 g)	≤0.5	≤0.5	≤1.0
Electrical conductivity (mS/cm)	≤0.8	-	-
Hydroxymethylfurfural (HMF) content (mg/kg)	≤40	≤40	≤30
Diastase activity (DN)	≥8	≥3	-
pH	-	-	2.5 to 3.8
Phenolic compounds	-	-	Present

Stingless bee honey has been reported to have a low pH value, which could be affected by several factors such as storage conditions and the extraction process. Furthermore, the pH itself affects the texture, stability, and shelf life of the honey. In addition, the acidity also gives extra flavour to the honey and is an indicator of microbial stability, as most bacteria cannot grow in an acidic environment [17]. Several reports that comply with the Malaysian Standards are from the species of *Tetragonula fuscobalteata* (Cameron, 1908), *Tetragonula laeviceps-pagdeni* complex, *Tetragonula testaceitarsis* (Cameron, 1901), *Tetrigona melanoleuca* (Cockerell, 1929), *Tetrigona apicalis* (Smith, 1857) [11], *Tetragonula laeviceps* [18], and *Tetrigona binghami* (Schwarz, 1937) [19,20].

Furthermore, the free acidity was not set by the Malaysian Standards but was set by the IHC and Vit et al. [15], in which the maximum free acidity of European honeybee honey is 50 and 85 meq/100 g. Some of the reported stingless bees that comply with both of the standards are *Geniotrigona thoracica* [21], *Melipona arufivestris*, *Trigona fuscipennis*, *Melipona quadrifasciata* (Lepeletier, 1836), *Melipona marginata* (Lepeletier, 1836), *Melipona mondury* (Smith, 1863), *Melipona scutellaris* (Latreille, 1811), *Scaptotrigona bipunctata* (Latreille, 1836), and *Tetragonisca angustula* (Latreille, 1811) [9].

Moisture is the second largest component in honey, which is attributed to the botanical origin of nectar, climate, and handling during harvesting. Furthermore, the moisture content is considered an important component in honey, as it could affect the viscosity, specific weight, maturity, flavour, and crystallisation [22]. Moisture content in stingless bee honey is reported to be higher than European honeybee honey, which is contributed by the benefit of abundant rainfall and high humidity in a rainforest [20]. Several reports that comply with the Malaysian Standards and those proposed by Vit et al. [15] are from the *Tetrigona apicalis* (Smith, 1857), *Tetrigona melanoleuca*, *Melipona marginata*, *Melipona quadrifasciata*, *Melipona flavolineata* (Friese, 1900), *Tetrigona binghami* and *Homotrigona fimbriata* (Smith, 1857) species [11,19,20,23].

Ash content is also used to measure the quality of honey, as it represents the mineral content present and can also be used to evaluate the nutritional value of honey, which is mostly affected by the potassium content [24]. The mineral content that correlates to ash content is due to the composition of the source of plant nectar from which the nectar-bearing plant absorbs minerals from the soil [7]. Some of the reports of ash content that comply with all standards are from the species *Geniotrigona thoracica* [19,21,25,26], *Scaptotrigona mexicana* (Lepeletier, 1836) [27], *Heterotrigina itama* [20,26], *Lepidotrigona doipaensis* (Schwarz, 1939), *Lepidotrigona flavibasis* (Cockerell, 1929), *Lepidotrigona terminata*, *Lisotrigona furva* (Engel, 2000), *Tetragonilla collina* (Smith, 1857) [11], *Melipona bicolor* (Lepeletier, 1836), *Melipona quadrifasciata*, *Melipona marginata*, and *Scaptotrigona bipunctata* [23].

According to the IHC Standards, electrical conductivity should not be more than 0.8 mS/cm, whereas Vit et al. [15] and the Malaysian Standards do not define any threshold. Some of the reports that comply with the standard are from the species *Scaptotrigona Mexicana* [27], *Geniotrigona thoracica* [19,25], *Heterotrigona Bakeri* [19], *Lepidotrigona terminata* [25], *Tetragonula laeviceps* [25,28], and *Scaptotrigona bipunctata* [9,23].

The parameters used to evaluate freshness and overheating of honey are the hydroxymethylfurfural (HMF) content and diastase activity. HMF is formed by breaking down fructose in the presence of acid, and its value increases when heated, during longer time storage, or during adulteration using sugar syrup [29]. However, stingless bee honeys are usually accused of being adulterated due to the high HMF content. Apparently only IHC and Vit et al. [15] have proposed standards to set a threshold of a maximum of 40 mg/kg, whereas the Malaysian Standards do not state any threshold. The stingless bee species that comply with both standards are *Scaptotrigona mexicana* [27], *Geniotrigona thoracica*, *Lepidotrigona terminata* [25], *Lepidotrigona doipaensis*, *Lepidotrigona flavibasis*, *Lisotrigona furva*, *Tetragonilla collina*, *Tetragonula fuscobalteata*, *Tetragonula laeviceps pagdeni complex*, *Tetragonula testaceitarsis*, *Tetrigona apicalis*, and *Tetrigona melanoleuca* [11].

2.1. Antioxidant Properties

Honey is considered to be a natural antioxidant, as it can help prevent damage to cells. The antioxidants properties of honey vary in each variety due to various geographical regions [30]. It has been reported that the antioxidant activity of stingless bee honey was triple the value of raw European honeybee honey and quadruple the value of processed honey [13]. The antioxidant potential of honey is not only affected by the total phenolic compounds of honey but also by the composition of flavonoids, which could significantly reduce oxidative stress [31]. However, Tuksitha et al. [30] reported that antioxidant activities also could be influenced by the protein content, which can be represented by the phenolic and flavonoids compounds, total phenolic content, total flavonoid content, and antioxidant capacity.

2.1.1. Phenolic and Flavonoid Compounds

Phenolics are a heterogenic group of compounds developed by the secondary metabolism of plants, and they can be divided into two groups: flavonoids and non-flavonoids. Flavonoids are also known as phenolic acids, and their derivatives are flavanols, flavanones, and flavones. Examples of non-flavonoids are stilbenes, tannins, and lignins [32]. According to Tungmunnithum et al. [33], both flavonoids and many other phenolic components have been reported for their effectiveness as antioxidants, anticancer, antibacterial, and cardioprotective agents; anti-inflammation; and promoting the immune system. According to Zulhilmi Cheng et al. [34], stingless bee honey is reported to have higher phenolic content compared to European honeybee honey, which is due to the stingless bee being smaller, thus enabling it to collect nectar from different species of flowers. Furthermore, Ávila et al. [35] stated that while building and sealing the hive, stingless bees combine their salivary secretion from the abdomen glands and beeswax; thus, the phytochemical composition of the honey could be attributed to the phytochemicals in the cerumen. However, the phenolic composition of stingless bee honey varies according to floral and geographical origin and the preference of each bee species during foraging [36].

In recent years, reports of individual phenolic compounds found in stingless bee honey have been scarce. Table 2 summarises individual phenolic compounds from Malaysian, Brazilian, and Cuban stingless bee honey. According to the Malaysian Standards [16], good-quality stingless bee honey is characterised by the presence of benzoic acid, phenylpropanoic acid, 4-hydroxybenzoic acid, 4-hydroxyphenylacetic acid, vanillic acid, protocatechuic acid, and *p*-coumaric acid. Referring to Table 2, almost all reported stingless bee honey complies with the Malaysian Standards, which consist of *p*-coumaric acid, protocatechuic acid, vanillic acid, and 4-hydroxybenzoic acid [31,35–39]. However, one species of stingless bee honey—*Melipona scutellaris* (Latreille, 1811), from Brazil—does not contain any phenolic compounds that match the Malaysian Standards and thus does not qualify as good-quality honey in Malaysia [39].

The most abundant phenolic compounds discovered in the 12 species of stingless bee honey listed in Table 2 are *p*-coumaric acid and naringenin, followed by salicylic acid, protocatechuic acid, caffeic acid, taxifolin, aromadendrin, and quercetin. According to Ranneh et al. [40], the phenolic acid ratio is usually higher than that of flavonoids in honey. The author also stated that gallic acid, caffeic acid, *p*-coumaric acid, and sinapic acid are proven to be easily absorbed by the human intestine despite the differences in kinetic efficacy. Reports on the detection of *p*-coumaric acid were discovered in honey of the *Heterotrigona itama* [31,39], *Scaptotrigona bipuncatata* [36,38], *Trigona hypogea* [36], *Tetragonisca angustula* [36,38], *Tetragona clavipes* [36,38], *Melipona marginata* [36,38], *Melipona quadriasciata* [35,36,38], *Melipona bicolor* [35,38], *Melipona mondury* [38], and *Melipona rufiventris mondory* species [38]. Next, also one of the most abundant chemical compounds found in stingless bee honeys, naringenin has been found in *Heterotrigona itama* [39], *Scaptotrigona bipuncatata* [35,36,38], *Trigona hypogea* [36], *Tetragonisca angustula* [36,38], *Tetragona clavipes* [36,38], *Melipona marginata* [38], *Melipona quadriasciata* [38], *Melipona bicolor* [38], *Melipona mondury* [38], and *Melipona rufiventris mondory* species [38]. As shown in Table 2, the presence of quercetin was reported in the honey of eight stingless be species, namely, *Scaptotrigona bipunctata* [35,36], *Melipona marginata* [35,36], *Tetragonisca angustula* [36,38], *Melipona quadriasciata* [35,36,38], *Melipona bicolor* [35], and *Heterotrigona itama* [39].

2.1.2. Total Phenolic Content

In a study of the phytochemical and antioxidant activities of Malaysian stingless bee honey by Maringgal et al. [41], it was discovered that the total phenolic content (TPC) in the honey varied according to geographical regions and that the value ranged from 3.045 to 9.370 mg GAE/100 g FW. The author stated that the value of TPC varied due to the variation in the source of pollen around the cultivated location. A study by Keng et al. [17] found that TPC values were different for honey collected from three regions, with values ranging from 525.16 to 1169.36 mg GAE/kg. The author explained that different values of TPC show that despite the honey being produced by the same species of stingless bees, the TPC value was affected by the different pollen of different botanical origins.

In addition, a study *of Heterotrigona itama* honey by Nuratiqah et al. [8] with a total of four honey samples in which each sample was collected from different parts of Peninsular Malaysia showed different values of TPC, ranging from 52.71 to 80.71 mg GAE/100 g. The author mentioned that the different values of TPC were not only influenced by geographical and botanical factors but also together with the selective floral behaviour and the longer and earlier foraging time of the bees. On the other hand, Ismail et al. [39] reported in their study that *Apini* and *Meliponini* foraging activities influence the phenolic content of different types of Malaysian honey, and the TPC values of stingless bee honey were reported to be lower than European honeybee honey. This may be due to the seasonal effect of the monsoon season during harvesting, which leads stingless bees to have fewer foraging trips and suffer from floral scarcity.

Table 2. Individual phenolic compounds in stingless bee honey.

Phenolic Compounds	Stingless Bee Species/Reference										
	Heterotrigona itama	***Scaptotrigona bipuncatata***	***Trigona hypogea***	***Tetragonisca angustula***	***Tetragona clavipes***	***Melipona marginata***	***Melipona quadriasciata***	***Melipona bicolor***	***Melipona beecheii* (Bennet, 1831)**	***Melipona mondury***	***Melipona scutellaris***	***Melipona rufiventris mondory***
Chlorogenic acid	[31]					[36]	[38]			[38]		
Coumaric acid									[37]			
p-coumaric acid	[31,39]	[35,36,38]	[36]	[36,38]	[36,38]	[36,38]	[35,36,38]	[35,38]		[38]		[38]
Salicylic acid		[36,38]	[36]	[36,38]	[36,38]	[36,38]	[38]	[38]		[38]		[38]
Protocatechuic acid	[31]	[36,38]		[36,38]	[36,38]	[36,38]	[38]					[38]
Ferulic acid		[36]		[36]	[36]		[36]					
Mandelic acid		[36,38]		[36]								
Rosmarenic acid						[36]	[36,38]	[38]			[38]	
Vanillic acid			[36]	[36]		[36]	[36,38]	[38]				
Caffeic acid	[39]		[36]	[36,38]		[38]	[36,38]	[38]		[38]		
Ellagic acid	[39]	[35]				[35]	[35]	[35]				
Dihydrocaffeic acid									[37]			
Sinapic acid							[38]					
TRANS ferulic acid	[39]			[38]	[38]	[38]		[38]		[38]		
Syringic acid	[39]	[38]		[38]		[38]	[38]					[38]
4-(hydroxy-methyl) benzoic acid		[38]										[38]
4-aminobenzoic acid				[36]								
Benzoic acid	[39]											
Trans-cinnamic acid	[39]											
Epicatechin	[31]											
Rutin	[31]											
Rutin hydrate	[39]											
Catechin	[31]											
Naringenin	[39]	[36,38]	[36]	[36,38]	[36,38]	[38]	[38]	[38]		[38]		[38]
Aromadendrin		[36]	[36]	[36,38]	[36,38]	[36,38]	[36,38]	[38]		[38]		[38]
Taxifolin		[36,38]	[36]	[36,38]	[36,38]	[36,38]	[38]	[38]		[38]	[38]	[38]
Isoquercetin		[36,38]				[36]	[38]			[38]		
Vanilin								[38]				
Quercetin	[39]	[35,36]		[36,38]		[35,36]	[35,36,38]	[35]				
Syringaldehyde		[36]	[36]	[38]		[36,38]						
Carnosol				[38]		[36]	[36,38]			[38]		
Scopoletin				[36]			[36]					
Eriodictol		[38]	[36]	[36,38]	[36,38]		[36,38]					[38]
Umbelliferone							[36,38]					
Hesperitin	[39]	[35]				[35]	[35]	[35]				
C-pentosyl-c-hexosyl-apigenin isomer								[37]				
Quercetin deoxyhexosyl hexoside									[37]			
Apigenin trihexoside									[37]			
Kaempferol deoxyhexosyl hexoside									[37]			
Kaempferol	[39]								[37]			
Isorhamnetin deoxyhexosyl hexoside								[37]				
Isorhamnetin									[37]			
Luteolin	[39]								[37]			
Bis-methylated quercetin									[37]			
Apigenin						[38]	[38]	[38]	[37]	[38]	[38]	
Methyl luteolin									[37]			
Methyl quercetin									[37]			
Hispidulin							[38]					
Chrysin	[39]						[38]					
Mirecetrin							[38]					[38]
Sinapaldehyde						[38]						

2.1.3. Total Flavonoid Content

A study of the influence of the origin and bee species with regard to the antioxidant properties by Shamsudin et al. [13] showed that the total flavonoids of *Heterotrigona itama* and *Geniotrigona thoracica* honey range from 2.8 to 9.31 mg QE/100 g. In that study, honey was collected from different locations across Peninsular Malaysia, and the author stated that the flavonoid content varied according to different botanical and geographical origins of nectar collected by the bees. Next, a study by Tuksitha et al. [30] concerning the antioxidant capacity of honey produced by stingless bees, namely, *Geniotrigona thoracica*, *Heterotrigona itama*, and *Heterotrigona erythrogastra* (Cameron, 1902), found that flavonoid content ranged from 12.41 to 17.67 mg/mL, with *Heterotrigona itama* demonstrating the highest value. The author stated that phenolic and flavonoid compounds in the honey provided the ability to donate an electron from a hydroxyl group to an unpaired electron of free radicals, which is related to the reducing power.

A study by Ya'akob et al. [42] on various Malaysian stingless bee honey samples from the *Trigona* sp. showed that the total flavonoid content ranged from 36.67 to 194.98 mg GA/100 g. The author also stated that phenolic and flavonoid content make for the strong antioxidant content of honey, which has potential in scavenging free radicals. Furthermore, a study by Ranneh et al. [43] comparing European honeybee honey with stingless bee honey revealed that stingless bee honey has a higher flavonoid content than European honeybee honey, for which the values were 97.88 to 101.5 mg CE/kg and 64.72 to 66.98 mg CE/kg, respectively. The author stated that the high value of polyphenols in stingless bee honey results in higher colour intensity.

2.1.4. Antioxidant Capacity

According to Martinello and Mutinelli [44], each method of determining antioxidant capacity will have a different result. This is due to antioxidants responding differently to different radical or oxidant stress, and no method can precisely reveal all radical sources or antioxidants in a compound. Maringgal et al. [41] used a 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay to evaluate honey antioxidant capacity, for which the result ranged from 2.77% to 44.05%. The study showed a significant correlation of DPPH activity with the phenolic compounds of stingless bee honey, for which the high phenolic content resulted in low DPPH activity. Alvarez-Suarez et al. [37] used a DPPH assay to investigate stingless bee honey and European honeybee honey. The antioxidant capacity of stingless bee honey via the DPPH assay was 42.23 μmol TE/100 g, whereas for European honeybee honey it was 31.06 μmol TE/100 g. The author stated that the chemical composition of honey is attributed to bee species and floral and geographical origin.

Biluca et al. [36] used a ferric reducing antioxidant power (FRAP) assay to assess the reduction capacity of Brazilian stingless bee honey, for which the value ranged from 67.5 to 734.5 μmol Fe^{+2} 100/g. The author used eight different honey samples, which were produced by *Scaptotrigona bipunctata*, *Melipona marginata*, *Tetragonisca angustula*, *Trigona hypogea*, *Melipona quadrifasciata*, and *Tetragona clavipes*, and the highest FRAP value was from *Tetragonisca angustula* honey. Tuksitha et al. [30] also used a FRAP assay in determining the antioxidant capacity of honey. The study investigated three species of bees, *Geniotrigona thoracica*, *Heterotrigona itama*, and *Heterotrigona erythrogastra*, for which the results showed that the antioxidant capacity of the stingless bee honey ranged from 25.78 to 50.66 mM of Fe^{2+}/100 g, with *Heterotrigona itama* being associated with the highest value. Kek et al. [45] found that the antioxidant activity assessed using a FRAP assay by *Heterotrigona itama* was twice as high as that of European honeybee honey, which ranged from 19.05 to 23.34 mg AAE/100 g.

Generally, the concept of a 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid (ABTS) scavenging assay is similar to the DPPH scavenging assay, which involves the affinity activity of free radicals. Antioxidant activity is determined by the capability of the test sample to transfer an electron to the ABTS radical cation through the decolourisation of the radical cation [31]. The author also used an ABTS scavenging assay to determine the antioxidant content of unifloral and multifloral stingless bee honey in which the ABTS inhibition ranged from 15.61% to 65.77%. The study showed that unifloral honey types hold higher antioxidant content than multifloral honey types and concluded that the antioxidant content of honey is attributed to the plant source, geographical origins, climate, and methods of processing [31]. In addition, Badrulhisham et al. [46] also used an ABTS assay to determine honey antioxidant content. Stingless bee honey was collected from three different locations across Malaysia for which the antioxidant levels ranged from 216.18 to 2006.87 µg TEAC/g. The study also showed a positive correlation of antioxidant levels with the phenolic compounds of stingless bee honey.

A study by Ranneh et al. [43] investigated the antioxidant capacity of stingless bee honey from *Trigona* sp. and European honeybee honey using the oxygen radical absorbance capacity (ORAC) assay, and revealed that stingless bee honey has a higher antioxidant capacity than European honeybee honey, at 29.56 to 89.44 µm TE/g and 22.28 to 75.47 µm TE/g, respectively. The study showed a significant correlation of polyphenol content with antioxidant capacity, as high polyphenol content was detected in the stingless bee honey and attributed to high antioxidant potential. Finally, a study by Biluca et al. [38] using an ORAC assay to determine the antioxidant capacity of stingless bee honey investigated nine different stingless bee honey samples collected in Brazil and showed that the antioxidant capacity varied from 199 to 667 µm TE 100/g. This study also found a significant correlation of phenolic compounds with antioxidant capacity.

2.2. Antimicrobial

It was reported that the stingless bees have been inhabiting Earth longer than European honeybees, since 65 million years ago, and their honey has higher antimicrobial activity [47]. Despite honey being produced globally, the composition and antimicrobial activity could still be variable due the difference in botanical origin and geographical and entomological sources [48] Some of the factors that have been reported to affect the antimicrobial activities of honey are phytochemicals, acidity, high osmolarity, and the presence of hydrogen peroxide [49].

Table 3 summarises the antimicrobial activity of various stingless bee honey samples from Malaysia, Thailand, the Western Amazon, Mexico, Trinidad and Tobago, Costa Rica, Brazil, and India. The antibacterial properties of honey have been acknowledged in traditional medicine for many years, with the healing properties attributed to the chemical composition, including the presence of hydrogen peroxide and other non-peroxide factors. Some of the non-peroxide elements that affect the antibacterial activities are phenolic compounds and flavonoids [30]. However, as for hydrogen peroxide, it is influenced by glucose oxide and catalase, which are enzymes in honey. The function of glucose oxide is to induce the production of hydrogen, whereas the catalase function is to destroy hydrogen peroxide. Thus, both of these enzymes preserve the nutritional content of honey [50].

On the other hand, a study by Ávila et al. [35] reported that besides osmotic properties and hydrogen peroxide, the antimicrobial activity of stingless bee honey might also be influenced by polyphenol content and low pH. This agrees with Fatima et al. [51] and Jibril et al. [52], who stated that it has been presumed that the antibacterial property of honey is affected by osmolarity, pH, phenolic compounds, and many other elements. Not all types of honey possess the same level of antibacterial activity, as it is mostly influenced by several factors such as botanical origin and the source of nectar [25].

It has been proven that stingless bee honey has the potential to inhibit bacteria [8,18,25,30,53–58]. Researchers Hasali et al. [58] stated that honey produced by *Heterotrigona itama* showed greater inhibition of *P. aeruginosa* compared to commercial antibiotics, indicating better antibacterial activity against pathogenic bacteria. A report showed that phenolic compounds such as coumaric acid, ferulic acid, salicylic acid, and gallic acid found in stingless bee honey could contribute to antifungal activity that prevents anthracnose disease on papaya caused by *Colletotrichum brevisporum* [59]. Next, a study on three stingless bees, namely, *Geniotrigona thoracica*, *Heterotrigona itama*, and *Heterotrig-*

ona erythrogastra, reported that all three stingless bee honeys had antifungal activity against *Alternaria brassicae* [30].

A study of the antifungal activity of stingless bee honey by Hau-Yama et al. [60] reported that honey produced by *Melipona beecheii* was able to inhibit growth of *Candida albicans*. According to the author, flavonoids present in the honey helped inhibit the fungus and the origin of the nectar and pollen collected by the stingless bee, which when added to components in the digestive tract of the bees may boost antifungal activity. A study of the antifungal effect of three local Malaysian honey samples by Hamid et al. [61] demonstrated that stingless bee honey has the best antifungal activity compared to *Tualang* and *Acacia* honey against *Candida albicans* and *Aspergillus niger*. The author stated that the stingless honey used for total growth inhibition of the fungus can be as low as 10% (v/v) concentration. Maringgal et al. [62] investigated the biosynthesis of calcium oxide nanoparticles mixed with stingless bee honey, which was named CaO Nps. The study tested the antifungal activity of CaO Nps using in vivo and in vitro assays against *Colletotrichum brevisporum*. The in vitro result showed that 15% CaO Nps inhibited the fungus growth to the smallest mycelial diameter, whereas in vivo showed strong protection in papaya fruit against the fungus of as low as 40% disease incidence during 12 days of storage at room temperature (24−28 °C).

Table 3. Antimicrobial activity of stingless bee honey.

Study Population	Stingless Bee Species	Origin	Key Findings	Reference
Pseudomonas aeruginosa (ATCC 10145) and *Streptococcus pyogenes (ATCC 19615)*	*Trigona* sp.	Malaysia	The stingless bee honey used was able to inhibit the growth of two bacterial species: *P. aeruginosa* and *Streptococcus pyogenes*, at 25.2 ± 0.6 mm and 26.7 ± 1.0 mm, respectively.	[53]
Colletotrichum brevisporum	*Trigona* sp.	Malaysia	The results of the study showed that synthesis of CaO Nps was able to inhibit the fungus growth in as low as 15% concentration. It is stated that due to the size of Nps, better penetration, absorption, and migration into the fungi cell results in better antifungal action.	[62]
Bacillus subtilis ATCC 21332, *Staphylococcus aureus ATCC 25923*, *P. aeruginosa ATCC 27853*, and *Escherichia coli ATCC 11775*	*Heterotrigona itama*	Malaysia	*H. itama* honey was able to inhibit growth of all the bacteria studied. The honey was more effective at inhibiting *B. subtilis* and *S. aureus* than *P. aeruginosa* and *E. coli*. The author stated it may be due to the outer membranes of *E. coli* and *P. aeruginosa*, which have greater resistance to the morphological changes caused by the honey.	[8]
S. aureus (ATCC 25923 and *ATCC 33591)* and *E. coli (ATCC 25922* and *ATCC 35218)*	*G. thoracica* and *H. itama*	Malaysia	Greater antibacterial effect was observed in *H. itama* honey, of which the inhibition zones demonstrated were 0.8–1.3 cm, whereas *Geniotrigona thoracica* honey's inhibition zone was 0.9–1.2 cm for the tested population.	[63]
Gram-positive bacteria; *S. aureus (ATCC11632)*, *B. subtilis (ATCC11774)*, and three Gram-negative bacteria; *E. coli (ATCC10536)*, *Serratia marcescens (ATCC13880)*, and *Alcaligenes faecalis (ATCC15554)*	*H. itama*, *H. erythrogastra*, *Tetrigona apicalis*, *Lepidotrigona terminata*, *T. melanoleuca*, *T. bingami*, *G. thoracica*, and *Homotrigona fimbriata*	Malaysia	*Homotrigona fimbriata* honey showed the highest antimicrobial activity, with inhibition of four of five tested bacteria species. However, *H. erythrogastra* did not inhibit any pathogen, though it had the lowest pH value of 1.83, and the study indicated little correlation of high acidity with high antimicrobial activity.	[47]
E. coli, *Salmonella Thyphimurium*, *Klebsiella pneumonia*, *P. aeruginosa*, *Bacillus cereus*, and *S. aureus*	*H. itama*	Malaysia	*H. itama* honey showed broad antimicrobial activity against pathogens. Specifically, it could inhibit the growth of *B. cereus* and *S. thyphimurium*. The antimicrobial activity of the honey was not just attributed to its physicochemical properties but also to isolates present, which were *Bacillus* strains.	[54]
S. aureus (ATCC) 25,923 and *E. coli (ATCC 25,922)*, *Haemophilus influenzae (ATCC 19, 418)*, and *Streptococcus pyogenes (ATCC 19,615)*	*Melipona favosa* (Fabricius, 1798) and *Frieseomelitta nigra* (Cresson, 1879)	Trinidad and Tobago	Both stingless bee honey samples showed that they could inhibit all of the pathogens and had greater bactericidal activities when compared to European honeybee honey and artificial honey (produced by in vitro assay). The minimum inhibitory concentrations (MIC) of 2–16% and minimum bactericidal concentrations (MBC) of 2–32% of the stingless bee honey were lower than those of European honeybee honey and artificial honey of 16–32%.	[64]
B. cereus TISTR 2372, *P. aeruginosa TISTR 1287*, *S. aureus TISTR 1840*, and *Salmonella Typhimurium TISTR 1469*	*Tetragonula laeviceps*	Thailand	The stingless bee honey showed that it could inhibit all of the microorganism species' growth rates successfully. The MIC and MBC value of the honey was in the range of 10–30% and 25–50%, respectively. The authors hypothesised that improving dehydration and carbohydrate elimination as well as isolation and extraction of phenolic and flavonoid compounds could provide better antimicrobial activity results.	[18]
E coli ATCC 25922, *Klebsiella pneumoniae ATCC 4352*, *P aeruginosa ATCC 15442*, and Gram-positive strains of *Enterococcus faecalis ATCC 29212*, *S. aureus ATCC 25923*, *Streptococcus pneumoniae ATCC 11733*, *S chromogenes (LB03)*, and *S. aureus (LB14)*	*Melipona eburnea* (Friese, 1900), *Melipona grandis* (Guérin-Méneville, 1844), *Melipona flavolineata* (Friese, 1900), and *Melipona seminigra* (Friese, 1903)	Western Amazon	All of the stingless bee honey samples displayed antibacterial activity against all bacteria except *E. coli*. The MIC and MBC values of the tested honey were both in the range of 1.56–25%.	[55]
Candida albicans	*Melipona beecheii*	Mexico	The study showed that stingless bee honey could inhibit fungus growth at 35% concentration when tested using the agar dilution method.	[60]

Table 3. *Cont.*

Study Population	Stingless Bee Species	Origin	Key Findings	Reference
S. aureus, *E. coli*, *Klebsiella pneumonia*, Methicillin-resistant *Staphylococcus aureus* (MRSA), *P. aeruginosa*, and *Acinetobacter baumannii.*	n.d.	India	The stingless bee honey alone could inhibit all of the pathogen species growth. The study demonstrated that the combination of honey, gelatine, and curcumin had better antibacterial activity than honey alone.	[56]
Colletotrichum brevisporum	*Trigona* sp.	Malaysia	Stingless bee honey at 15% concentration is the optimum in inhibiting and suppressing mycelial growth of the species *C. brevisporum.*	[59]
E. coli ATCC 25992, MRSA, *B. subtilis CGMCC 1.2428), P. aeruginosa PAO1*, *C. albicans ATCC 10231*, and *Aspergillus terreus 01*	*Tetragonisca angustula*	Costa Rica	The study showed that *Tetragonisca angustula* honey strongly inhibited *B. subtilis*, *S. aureus*, and *E. coli.* Against *P. aeruginosa*, no inhibition activity occurred. The antimicrobial activity of honey was due to the presence of isolates identified as *Streptomyces* sp.	[57]
Bacillus cereus, *S. aureus*, *Micrococcus luteus*, *E. coli*, *Enterobacter aerogenes*, *Alcaligenes faecalis*, *Aeromonas hydrophila*, and *Salmonella Typhimurium*	*H. itama*	Malaysia	The study showed that *Heterotrigona itama* honey inhibited all of the bacterial growth. The antibacterial activity of the honey was attributed to the presence of various bacteria, such as *Bacillus* spp.	[65]
Gram-negative (Klebsiella pneumoniae, *E. coli*, *Salmonella Typhimurium), Gram-positive (S. aureus*, *Listeria monocytogenes*, *Bacillus cereus)*, and *fungus (C. albicans).*	*Melipona bicolor*, *Melipona quadrifasciata*, *Melipona marginata*, and *Scaptotrigona bipuncatata*	Brazil	All of the stingless bee honey samples were able to inhibit all of the microorganisms. The study reported that the antimicrobial activity of stingless bee honey was twice as high as European honeybee honey when compared to previous reported findings of MIC.	[23]
Gram-positive bacteria were used, namely, *S. aureus*, *S. intermedius B*, *S. xylosus*, *and Streptococcus alactolyticus*, as well as Gram-negative bacteria, namely, *Citrobacter koseri*, *E coli*, *Klebsiella pneumonia*, *P. aeruginosa*, *Salmonella enterica* Serovar *Choleraesuis*, and *Vibrio parahaemolyticus*	*G. thoracica* and *H. erythrogastra*	Malaysia	The study showed that honey samples produced by *Geniotrigona thoracica* and *Heterotrigona erythrogastra* were able to inhibit the growth of all of the various bacterial species tested. By way of contrast, honey produced by *Heterotrigona itama* showed no inhibitory activity against *K. pneumonia, S. enterica*, and *V. parahaemolyticus.*	[30]
Gram-negative and Gram-positive bacteria: *S. aureus*, *Bacillus cereus*, *E. coli*, *Salmonella Typhimurium*, and *P. aeruginosa*	*H. itama*	Malaysia	All of the stingless bee honey samples showed great inhibitory activities against the pathogens, as the honey has a broad spectrum of antibacterial activity. The study showed that *E. coli* was the most sensitive pathogen to the stingless bee honey, which showed that the diameter of the inhibition zone ranged from 26.5 to 32.8 mm.	[58]
C. albicans and *Aspergillus niger.*	*Trigona* sp.	Malaysia	The study showed that stingless bee honey at 10% concentration could inhibit the growth of both fungus species.	[61]
Gram-positive and Gram-negative bacteria were used: *S. aureus ATCC25923* and *ATCC29213*, *S. epidermidis ATCC12228*, *Enterococcus faecalis ATCC29212*, *Enterococcus faecium ATCC6569*, *Streptococcus mutans UA159*, *Streptococcus pyogenes ATCC19615*, *E. coli ATCC25922* and *ATCC8739*, *Salmonella enterica serovar Enteritidis ATCC13076*, *Klebsiella pneumoniae ATCC700603*, and *P. aeruginosa ATCC27853* and *ATCC9027.*	*S. bipunctata* and *S. postica*	Brazil	The study showed that both of the honey samples possess antimicrobial activity against bacteria, with the inhibition zone for Gram-positive strains in the range of 13.9–18.3 mm and Gram-negative strains in the range of 8.14–10.28 mm. It also showed that the combination of both honey samples has the potential for the development of new broad-spectrum antimicrobials that have the potential to prevent the emergence of resistant bacterial strains.	[66]

2.3. Anticancer Potential of Stingless Bee Honey

In the context of cancer treatment, once it has been diagnosed most cancer cannot simply be removed surgically, but rather requires destructive radiotherapy or chemotherapy. Both methods could result in many unfavourable severe side effects for patients and in worst-case scenarios, some cancer cells have evolved to resist current chemotherapeutic agents [67]. Thus, finding a novel approach to treating cancer is important. The interest in using natural products is increasing due to the trend of researchers seeking new substances that could treat cancer and extend the life expectancy of patients [68]. In preventing cancer, it has been recommended to take honey produced by bees. Inflammatory cells are well-known controls of a cancer environment; thus, inflammation is crucially important to reduce cancer progression [3].

In recent years, reports about using stingless bee honey in treating cancer cells have been scarce. Table 4 shows compiled reports concerning the potential of stingless bee honey anticancer properties. Oral squamous cell carcinoma (OSCC), as shown in Figure 2, is a pathological type of oral cancer, and it is ranked the eighth most common cancer in the world, as it comprises 90% of oral cancers and 5% of all cancers per year [69]. A recent study by Mahmood et al. [70] on stingless bee honey for treating OSCC showed promising results as a novel treatment. The study used honey from Malaysian *Heterotrigona itama* stingless bees against an OSCC cell line, HSC-2. Results from a 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT) assay showed that inhibition of 50% HSC-2 only needed a 0.84% honey dose, whereas for the maximum inhibition of the cells it only needed a 10% honey dose. The author suggested that the anti-cancerous property of the honey may be due to the presence of phenolic and flavonoid compounds.

Figure 2. Oral squamous cell carcinoma on human tongue. Reprinted with permission from Ref. [71]. 2017, Dental Update.

According to Waks and Winer [72], breast cancer can be divided into three types: hormone receptor-positive breast cancer, which has either an estrogen receptor (ER) or progesterone receptor (PR) protein in the cancer cells; ERBB2-positive, which has high levels of ERBB2 proteins in the cancer cells; and lastly, triple-negative breast cancer, which does not have ER, PR, or ERBB2 protein in the cancer cells. Badrulhisham et al. [46] found that stingless bee honey could be use to treat breast cancer. Two breast cancer cell lines were tested—MDA-MB-231 and MCF-7—using an MTT assay. The ideal stingless bee honey samples tested showed the greatest cytotoxic activity towards ER- and PR-positive cells (MCF-7) compared to triple-negative breast cancer cells (MDA-MB-231).

Malignant gliomas are the most common form of primary brain tumours and aggressive tumours, with a survival rate of usually up to 15 months after diagnosis. Over the past years, with advances in cytotoxic therapy regimens, targeted angiogenesis inhibitors, and novel therapeutic modalities, diagnosed patient survival has only increased modestly [73].

Recently, a study by Ahmad et al. [68] using stingless bee honey to combat malignant glioma showed positive results. The study used a *Heterotrigona itama* honey against malignant glioma cell line U-87 MG. Results from the cytotoxic activity showed that the highest cytotoxic effect was at a 10% dose of stingless bee honey with inhibition of 50% of U-87 cells. The author stated that the inhibition ability of honey depends on the bee product source, species, and type of cancer line used.

Colorectal cancer is one of the most dreadful diseases, and the management of this cancer mainly includes surgical treatment, chemotherapy, and radiation therapy. However, all of these options affect normal cells and cause many side effects [74]. Even in advancing preventative strategies, screening programmes, and chemotherapy, the survival of a patient diagnosed with metastatic colon cancer is only around 20 months [75]. A study of stingless bee honey in treating colon cancer by Yazan et al. [76] revealed the chemopreventive properties of stingless bee honey (*Trigona* sp.) with respect to Sprague–Dawley rats that were induced with azoxymethane. The results showed that the development of aberrant crypt foci (ACF), aberrant crypt (AC), and crypt multiplicity were reduced along with no reduction in body weight. This means that stingless bee honey was not toxic to the animals. The author stated that phenolic compounds and caffeic acid phenethyl ester (CAPE) could be factors of anticancer properties in stingless bee honey.

Table 4. Anticancer potential of stingless bee honey.

Stingless Bee	Study	Findings	Reference
Heterotrigona itama	Oral squamous cell carcinoma (OSCC)	The study showed that *Heterotrigona itama* honey could inhibit cancerous cells. The stingless bee honey needed to inhibit 50% of cell growth was only less than 1% of the dose.	[70]
Trigona sp.	Breast	The study demonstrated the potential use of stingless bee honey in treating breast cancer. The author compared three different samples of stingless bee honey that were collected across Malaysia, and the results showed that the ideal honey sample was that which had the greatest cytotoxic activity towards ER- and PR-positive cells compared to triple-negative breast cancer cells.	[46]
Heterotrigona itama	Malignant glioma	The study displayed high anticancer activities of stingless bee honey, which can inhibit cell proliferation and prevent malignant glioma in cell lines.	[68]
Trigona sp.	Colon	The study reported potential chemopreventive properties of stingless bee honey against colon cancer cells.	[76]

3. Stingless Bee Propolis

Generally, propolis contains resins gathered by honeybees from their botanical sources mixed with saliva and beeswax inside the hive (Figure 3). Some of the roles of propolis are to seal cracks or openings, protect from threats, and most importantly, for breeding and food storage [77]. In addition, stingless bees also produce propolis called geopropolis, but with the addition of soil materials, which results in a less malleable resin compared to European honeybee propolis [78]. Propolis contains more than 150 compounds, which are a mixture of polyphenols, flavonoids, aglycones, phenolics, and ketones. Additionally, flavonoids and phenolic compounds have been reported as having antioxidant properties [79]. Currently, the needs to discover sources of antioxidant agents are very important, as humans commonly produce free radicals that could lead to cell damage and mutation [80].

Figure 3. Propolis produced by stingless bees inside a wooden beehive. Adapted with permission from Ref. [81]. 2020, Amalia et al. 2020.

3.1. Antioxidant Properties

A study by Fikri et al. [82] compared the antioxidant properties of propolis produced by *Tetragonula biroi*, *Heterotrigona itama*, and *Tetragonula laevicep* that was extracted using ethanol and water. The study of antioxidant activity was assessed using DPPH assays, and the results showed that ethanol extracts provided higher antioxidant activity. Another study on the antioxidant activities of stingless bee propolis by Pazin et al. [80] investigated three stingless bee propolis, namely, *Melipona quadrifasciata anthidiodes* (Lepeletier, 1836), *Tetragona clavipes*, and *Scaptotrigona* spp., with one European honeybee propolis. By using the DPPH assay method, the results showed that *Melipona quadrifasciata anthidiodes* propolis extract had the highest antioxidant activity.

Next, a study on *Heterotrigona itama* propolis extract by Akhir et al. [83] investigated the antioxidant activity from two extraction solutions, namely, ethanol and n-hexane. The study assessed the antioxidant activity by using FRAP assays and showed that ethanol extracts could produce higher antioxidant activity compared to n-hexane. According to Kasote et al. [84], FRAP assays have a strong positive correlation with total phenolics and flavonoids, with $r = 0.953$ and $r = 0.727$, respectively. Campos et al. [85] reported that the antioxidant activity of stingless bee propolis extract using ABTS assays showed five times higher antioxidant activity compared to the synthetic antioxidant butylated hydroxytoluene, which was the control sample. The authors also stated that the results produced by antioxidant capacity could be related to the chemical composition of propolis.

3.2. Chemical Composition

According to Ibrahim et al. [79], the chemical composition and biological activities of propolis are due to the botanical source, geographical area, and harvesting season. Overall, the chemical composition of stingless bee propolis is composed of aromatic acids, phenolic compounds, alcohols, terpenes, and sugars [84]. Table 5 summarises the reported chemical compounds found in stingless bee propolis originating from Malaysia, Brazil, Mexico, Thailand, the Philippines, Vietnam, and India. A total of 16 species of stingless bee samples are listed in Table 5, and the most abundant reported compounds are *p*-coumaric acid and gallic acid.

Table 5. Stingless bee propolis chemical compounds.

	Stingless Bee Species/Reference															
Chemical Compounds	***Scaptotrigona bipuncatata***	***Melipona quadrifasciata quadrifasciata* (Lepeletier, 1836)**	***Plebeia remota***	***Melipona quadrifasciata anthidioides***	***Tetragonula laeviceps***	***Tetrigona melanoleuca***	***Trigona* sp.**	***Melipona beecheii***	***Lisotrigona cacciae***	***Friesomelitta longipes***	***Tetragonula biroi***	***Tetragonisca angustula***	***Tetragonula fuscobaleata***	***Geniotrigona thoracica***	***Melipona fasciculata***	***Tetragonisca fiebrigi***
p-coumaric acid	[86]	[86–88]		[80,89]			[84]									[85]
p-coumaric hexoside acid			[89]													
Ferulic acid	[86]						[84]									
Isoferulic acid	[86]															
Drupanin (3-prenyl-4-hydroxycinnamic acid)	[86]															
Oleic acid	[86]															
Stearic acid	[86]															
Ellagic acid	[86]	[86]		[89]												
Cinnamic acid							[84]									[85]
Hydrocinnamic acid																[85]
Gallic acid		[86,88]		[89]	[90]	[90]	[84]					[88]			[91]	
Palmitic acid	[86]															
Anacardic acid	[86]								[92]							
Junicedric acid		[86]	[86]													
Mangiferonic acid		[86]														
Isomangiferolic acid		[86]														
Trans-communic acid		[86]														
Caffeic acid							[84]									
Pimaric acid			[86]													
Arachidonic acid			[86]													
Benzoic acid																[85]
Agathic acid			[86]													
Cupressic acid		[86]	[86]													
Isocupressic acid		[86]	[86]													
Kaurenoic acid																[85]
15-acetoxy-cupressic acid		[86]														
4-methoxybenzoic acid															[85]	
Hydrocinnamic acid ethyl ester															[85]	
3-phenyl-*p*-coumaric acid															[85]	
4-hydroxy-3(e)-(4-hydroxy-3-methyl-2-butenyl)-5-prenyl cinnamic acid	[86]															
3-hydroxy-2,2-dimethyl-8-prenyl- 2 h-1-benzopyran-6-propenoic acid	[86]															
Eicosapentaenoic acid	[86]															
Dicaffeoylquinic acid isomer	[86]															
Vicenin-2, e)-3-{4-hydroxy-3-[(e)-4-(2,3-dihydrocinnamoyloxy)-3-methyl-2-butenyl]-5-prenyl-phenyl}-2-propenoic acid	[86]															
Isoliquiritigenin	[86]															
Formononetin	[86]															
Biochanin a	[86]															
Kaempferol methyl ether	[86]															
Dihydrokaempferide	[86]															
Retusin 8-methyl ether,	[86]															
Artepillin c	[86]															
Artepillin c derivative	[86]															
Naringenin		[86,87]		[89]			[84]									
Methyl-naringenin				[89]												
Aromadendrin		[86,87]		[89]												
Methyl-aromadendrin			[89]													
Isosakuranetin		[86]														
Aromadendrin methyl ether	[86]															
Sugiol		[86]	[86]													
Cinnamoyl-coumaroyl-hexoside	[86]															
Dicoumaroyl-hexoside	[86]															
Digalloyl-cinnamoyl-hexoside	[86]															

Table 5. *Cont.*

Chemical Compounds	Stingless Bee Species/Reference															
	Scaptotrigona bipuncatata	*Melipona quadrifasciata quadrifasciata* (Lepeletier, 1836)	*Plebeia remota*	*Melipona quadrifasciata anthidioides*	*Tetragonula laeviceps*	*Tetrigona melanoleuca*	*Trigona* sp.	*Melipona beecheii*	*Lisotrigona cacciae*	*Friesomelitta longipes*	*Tetragonula biroi*	*Tetragonisca angustula*	*Tetragonula fuscobaleata*	*Geniotrigona thoracica*	*Melipona fasciculata*	*Tetragonisca fiebrigi*
Cinnamoyl-coumaroyl-galloyl-hexoside	[86]															
Dicoumaroyl-galloyl-hexoside	[86]															
Betuletol	[86]															
Totarol			[86]													
O-coumaroyl o-galloyl hexoside			[89]													
Di-o-galloyl o-cinnamoyl hexoside		[89]														
O-cinnamoyl o-galloyl hexoside			[89]													
O-galloyl hexoside				[90]												
O-cinnamoyl o-coumaroyl hexoside		[89]														
Luteolin-methyl-ether			[89]													
Quercetin-3-methyl-ether			[89]													
Pinocembrin		[87]				[90]										
Quercetin		[88]				[90]	[84]									
Kaempferol							[84]									
Phenethyl caffeate							[84]									
Pentacyclic triterpens							[93]									
Catechin		[87]														
Epicatechin		[87]														
Alkylresorcynols									[92]					[94]		
Triterpenes									[92]					[94]		
Homoisoflavanes									[92]						[91]	
Prenylated xantones									[92]							
7,4′-dihydroxy-5-methoxyhomoisoflavane						[92]										
10,11-dihydroxydracaenone C								[92]								
3-geranyloxy-1,7-dihydroxyxanthone							[92]									
7-geranyloxy-1,3-dihydroxyxanthone							[92]									
2,6,8-trihydroxy-5-geranyl-7-prenylxanthone						[92]										
A-mangostin									[92]				[95]			
Γ-mangostin													[95]			
Garcinone b									[92]							
Cycloartenone									[92]							
Lupeol									[92]							
Monoterpenes								[96]		[97]						
Sesquiterpenes										[97]						
Prenylated benzophenones										[97]						
Glyasperin a											[98]					
Propolin e											[98]					
Propolin a											[98]					
Vanillin		[88]														
Styrene								[96]								
Benzaldehyde								[96]								
Cinnamyl caffeate																[85]
Benzyl caffeate																[85]

Furthermore, after comparing the same species reported by Surek et al. [86], Hochheim et al. [87], and Torres et al. [88], *Melipona quadrifasciata quadrifasciata*, the chemical compositions of propolis were mostly dissimilar. The dissimilarities of the reported chemical composition were due to each author using a different method of identifying the chemical compounds. Location and period for collecting the propolis also caused dissimilarities in the chemical composition. Some of the common chemical compounds detected by the authors were *p*-coumaric acid [86–88], gallic acid [86,88], and aromadendrin [86,87]. Besides, by comparing the studies by Pazin et al. [80] and Rubinho et al. [89] on *Melipona quadrifasciata anthidioides* propolis, the common chemical compounds reported was only *p*-coumaric acid. Comparing all the species listed in Table 5, the most reported chemical compounds by the authors were gallic acids [84,86,88–90,98].

3.3. Antimicrobial

Ngalimat et al. [65] stated that only a very limited number of bacteria are present in *Heterotrigona itama* propolis, which may be due to the propolis having strong antimicrobial activity. Antimicrobial activity in stingless bee propolis may be attributed to the coactive activities of flavonoids and other chemical components [99]. In addition, the antimicrobial activity of stingless bee propolis may also be attributed to the method of extraction, osmotic effect, pH, presence of hydrogen peroxide, and phytochemicals properties [100].

Table 6 summarises the antimicrobial activity of various stingless bee propolis from Malaysia, Brazil, India, Brunei, and Thailand. Researchers Shehu et al. [101] showed that the stingless bee propolis extract effectively inhibited both *Candida albicans* and *Cryptococcus neoformans* fungi. According to the authors, phenolic and flavonoid compounds such as pinocembrin, morin, rutin, and quercetin present in the propolis may contact the cell wall of the fungus and cause cell death. On the other hand, a study by Dutra et al. [102] on the antileishmanial activity of a Brazilian stingless bee, *Melipona fasciculata*, showed that the stingless bee propolis effectively inhibited the protozoan growth that causes leishmaniasis, which is a serious infectious disease in tropical and temperate regions. The authors stated that the antileishmanial activity of the stingless bee propolis may be attributed to the presence of gallic acids and ellagic acids.

Table 6. Stingless bee propolis antimicrobial activity.

Study Population	Stingless Bee Species	Origin	Key Findings	Reference
Escherichia coli ATCC 25922, *E. coli* (ATCC 35218), *Klebsiella pneumoniae* (ATCC 13883), *K. pneumoniae* (ATCC 700603, *Pseudomonas aeruginosa* (ATCC 27853), *Enterococcus faecalis* (ATCC 29212), *E. faecalis* (ATCC 51299, methicillin-sensitive *Staphylococcus aureus (MSSA) ATCC 6538)*, and methicillin-resistant *Staphylococcus aureus* (MRSA, ATCC 33591)	*Scaptotrigona bipunctata* and *Melipona quadrifasciata*	Brazil	Extract from *Melipona quadrifasciata* geopropolis inhibited most of the growth of the sample microorganisms except for *E. coli*, *K. pneumoniae*, and *P. aeruginosa.* However, *S. bipunctata* extract did not show any inhibition. The antimicrobial activity of the extracts was attributed to the presence of diterpene compounds, gallic acid, and totarol.	[86]

Table 6. *Cont.*

Study Population	Stingless Bee Species	Origin	Key Findings	Reference
Staphylococcus aureus ATCC-29213 and *Bacillus subtilis* *ATCC-11774)* and two Gram-negative bacterial strains (*E. coli* ATCC-11775 and *P. aeruginosa* ATCC-27853)	*Geniotrigona thoracica*, *Heterotrigona itama*, and *Tetrigona binghami*	Brunei	Extracts from both geopropolis inhibited all of the growth of all the microorganisms. Furthermore, in comparison of both geopropolis extracts to the control antibiotic samples, rifampicin and streptomycin, the geopropolis extracts showed weaker microorganism inhibition of 7.0–13.0 mm, whereas that of the antibiotics was 12.4–14.8 mm.	[103]
Leishmania amazonensis	*Melipona fasciculata*	Brazil	Extract from the geopropolis inhibited the protozoan growth and effectively reduced infection of murine macrophages. The anti-*Leishmania* activity of the extracts was likely attributed to the presence of gallic acid and ellagic acid.	[102]
S. aureus ATCC-29213 and *B. subtilis* ATCC-11774, *E. coli* ATCC-11775, and *P. aeruginosa* ATCC-27853	*Heterotrigona itama*	Brunei	Geopropolis extracts inhibited the growth of all the microorganism species, most of which was stronger than the control antibiotic samples. The inhibition zones of geopropolis extracts were in the range of 7.3–17.0 mm, whereas the control antibiotic inhibition zones were in the range of 4.0–18.3 mm. Better inhibition zones were observed only for *E. coli*.	[99]
S. aureus ATCC 9144 and *Bacillus subtilis* ATCC 6633, *E. coli* ATCC 8739, *P. aeruginosa* ATCC 9027, and *Candida albicans* ATCC 10231	*Trigona* sp.	India	Extract from the geopropolis inhibited all of the growth of all the microorganism species. *Candida albicans* was the most sensitive (MIC = 0.5 to 8 mg/mL), whereas the least sensitive was *E. coli* (MIC = 20 to 40 mg/mL). However, the study showed no correlation of antimicrobial activity with phenolics and flavonoid contents.	[84]
B. cereus, *S. aureus*, *Micrococcus luteus*, *E. coli*, *Enterobacter aerogenes*, *Alcaligenes faecalis*, *Aeromonas hydrophila*, and *Salmonella* Typhimurium	*Heterotrigona itama*	Malaysia	This study showed the extract of beneficial bacteria from the geopropolis, and *Bacillus* spp. Could inhibit all of the evaluated microorganisms. It is known that *Bacillus* isolates are commonly found to eliminate unfavourable miroorganisms that could cause destruction of the bee colony.	[64]
S. aureus ATCC 25923, MRSA (clinic isolate), *E. faecalis ATCC 29212*, *E. coli* ATCC 25922, and *K. pneumoniae* ATCC 23883	*Melipona quadrifasciata* and *Tetragonisca angustula*	Brazil	Extract from both geopropolis extracts inhibited all the microorganism species' growth, and *M. quadrifasciata* showed stronger antimicrobial activity by showing lower MIC values (5–7 mg/mL).	[88]

Table 6. *Cont.*

Study Population	Stingless Bee Species	Origin	Key Findings	Reference
S. aureus ATCC 6538™, *S. aureus* ESA 175, *S. aureus* ESA 159, ATCC 43300™, *E. faecalis* ESA 201, *E. faecalis ESA 361*, *E. coli* ATCC 29998™, *E. coli ESA 37*, *E. coli* ESA 54, *P. aeruginosa* ATCC 15442, *P. aeruginosa* ESA 22, *P. aeruginosa* ESA 23, *Cryptococcus neoformans* ATCC 32264, *C. neoformans ESA 211*, *C. neoformans ESA 105*, *C. albicans* ATCC 10231™, *C. albicans* ESA 100, and *C. albicans* ESA 97	*Melipona orbignyi* (Guérin-Méneville, 1844)	Brazil	Geopropolis extracts inhibited all the microorganism species. In addition, it showed bactericidal and fungicidal activity against all of the evaluated microorganisms. The inhibition observed was in the sequence of *S. aureus* > *E. faecalis* > *E. coli* > *P. aeruginosa* > *C. neoformans* > *C. albicans*, with the MBC value ranging from 8.5 mg/mL for *S. aureus* to 36.1 mg/mL for *C. albicans.*	[104]
B. subtilis, *S. aureus*, *E. coli*, and *Salmonella*	*Heterotrigona itama*	Malaysia	Geopropolis extracts inhibited all the microorganism species. Additionally, the geopropolis extract using ethanol showed higher antimicrobial activity than extracts using hexane. Besides the method of extraction, osmotic effect, pH level, presence of the hydrogen peroxide, and phytochemicals likely affected the antimicrobial activity.	[83]
Streptococcus mutans	*Trigona sirindhornae*	Thailand	Extract of the propolis significantly inhibited bacterial growth. The inhibition value of extracts was 43.5 µg/mL.	[105]
C. albicans and *C. neoformans*	*Geniotrigona thoracica*	Malaysia	Extract from the geopropolis efficiently inhibited, with an MIC value of 1.56 mg/mL for both of the fungal species. The antifungal activity may be attributed to its phenolic and flavonoids compounds.	[101]
S. aureus ATCC 43300, *S. aureus* ESA 654, *S. epidermidis* ATCC 12228, *S. epidermidis* ESA 675, *Enterococcus faecalis* ATCC 43300, *E. faecalis* ESA 553, *K. pneumonia* ATCC 4352, *K. pneumoniae* ESA 154, *P. aeruginosa* ATCC 15442, *P. aeruginosa* ESA 22, *Proteus mirabilis* ATCC 43300, *P. mirabilis* ESA 37, *C. glabrata* ATCC 90030, *C. glabrata* ESA 123, *C. albicans* ATCC 90028, and *C. albicans* ESA 345.	*Tetragonisca fiebrigi*	Brazil	Extract from the geopropolis inhibited all the microorganism species. The inhibition was observed in the sequence of *S. aureus* > *S. epidermidis* > *E. faecalis* > *P. mirabilis* > *K. pneumonia* > *P. aeruginosa*, with the MIC value ranging from 1.5 mg/mL for *S. aureus* to 15.5 mg/mL for *P. aeruginosa.*	[85]

4. Stingless Bee Pollen

In general, bee pollen is a collection of pollen grains collected by bees from numerous botanical sources, which are mixed with nectar and digestive enzymes [106]. In addition, bee pollen is used as a food source [107]. Figure 4 shows an illustration of the process of stingless bees producing bee pollen, which starts with the bees collecting flower pollen and then bringing it to the hives to store it in cerumen pots [108]. During harvesting of bee pollen by humans, the destruction of the hive is inevitable for both stingless bees and European honeybees.

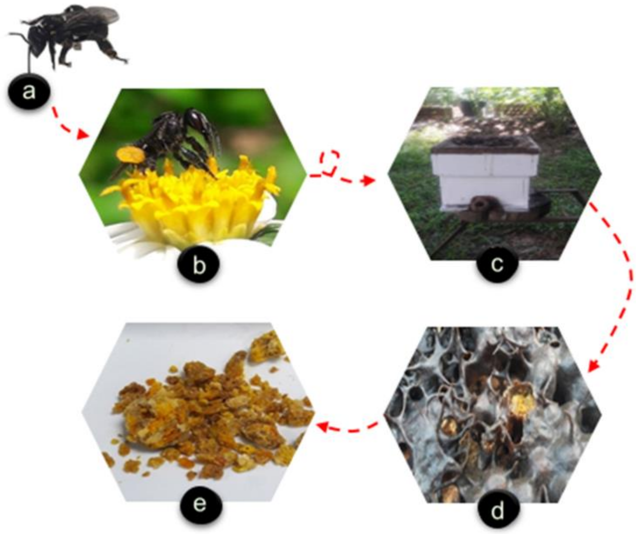

Figure 4. Process of stingless bees collecting and producing bee pollen: (**a**) stingless bee, (**b**) bee collecting pollen, (**c**) stingless bee bringing pollen to hive, (**d**) pollen stored in cerumen pots, and (**e**) harvested bee pollen. Reprinted with permission from Ref. [108]. 2021, MDPI.

The beneficial properties of bee pollen are associated with health benefits and antioxidant activity [109]. Due to its highly beneficial properties, bee pollen is gaining the attention of consumers as a functional food. In addition, bee pollen has been used as an alternative and complementary treatment for prostatitis, stomach ulcers, and infectious diseases [110]. Previously, stingless bee pollen has been reported to consist of more than 250 beneficial substances, i.e., sugars, lipids, carbohydrates, proteins, amino acids, vitamins, minerals, carotenoids, flavonoids, and macro- and micronutrients [111,112]. Due to difficulty in acquiring stingless bee pollen, its selling price is high [113].

Generally, the phenolic content of bee pollen is related to its antimicrobial, antimutagenic, antioxidative, anti-inflammatory, and antifungal properties [114]. The composition of bee pollen is attributed to the species, geographical origin, climate zone, soil fertility, nutritional values of the foraged plants, season, and extraction method of the pollen by the bees [115,116]. The major reported phenolic compounds found in stingless bee pollen are shown in Figure 5, which are rutin, hydroxycinnamic acids, salicin, and ellagic acid.

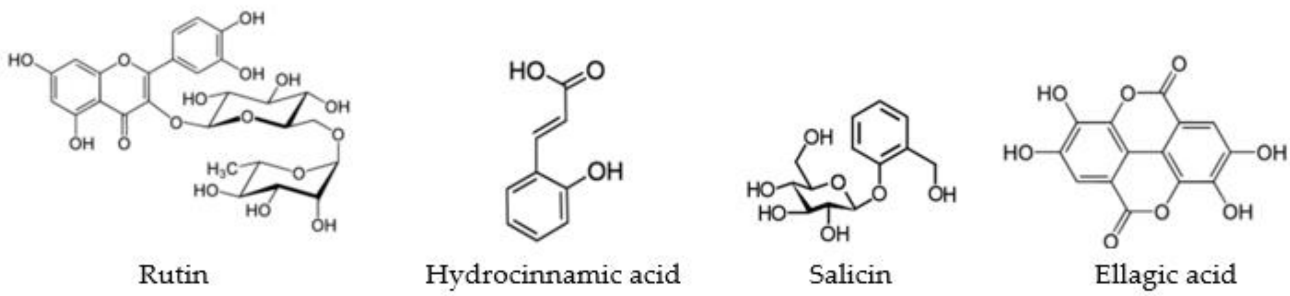

Figure 5. Most abundant phenolic compounds in stingless bee pollen.

Mohammad et al. [113] revealed that *Heterotrigona itama* contains probiotic bacteria in stingless bee pollen for which its antimicrobial activity effectively inhibits foodborne pathogens. A study by Carneiro et al. [117] on a Brazilian stingless bee, *Melipona compressipes manaosensis*, revealed that pollen produced by stingless bees contains active secondary metabolites that are a potential component for antibiotics and insecticides. Furthermore, Bárbara et al. [118] explained that in their study of a Brazilian stingless bee, *Mellipona mandacaia*, the stingless bee pollen was not contaminated by pathogenic microorganisms and was safe to be consumed. To date, information and studies on stingless bee pollen are scarce; thus, intensive study is needed for better understanding.

5. Future Trends

Currently, consumer awareness of the need for a healthy lifestyle has caused many industries to change from chemical-based products to organic or natural-based products. In this modern and digital era, consumers may easily track the source and discover information concerning products they consume or use, which encourages producers to provide better services. In addition, most of the world governments are trying to achieve the Sustainable Development Goals (SDG), which include good health and well-being, sustainable consumption and production patterns, and an ecological environment. The usage of stingless bee products, which include honey, propolis, and pollen, could contribute to achieving the SDGs. However, comprehensive studies of potential uses of stingless bee products are lacking, especially concerning their antioxidant, anticancer, and antimicrobial properties. Through this comprehensive review, we hypothesise that stingless bee products could revolutionise many industries such as agriculture, food processing, healthcare, pharmaceutical, cosmetic, and tourism due to their high nutritional and unique characteristics.

Stingless bee honey is the most studied product of stingless bees, as it is consumable and highly nutritional. It also has gained popularity due to its unique beneficial values. Researchers have been studying stingless bee honey as a bioactive agent in various industries, which include agricultural, medical, and cosmetic. As for other stingless bee products, propolis has also been highly studied after stingless bee honey due to its unique chemical constitution. Mainly stingless bee propolis products have only been studied as an extract for the health and cosmetics industries. Subsequently, after the stingless bee propolis extraction, it is thrown away. However, it could be used as a by-product for its elastic and hard properties.

However, due to the high demand and low supply of stingless bee products, the selling price is much higher than of common European honeybee honey. This high selling price for stingless bee products causes a conflict, as production and research capital might be higher than for common European honeybee products or other natural products. In addition, due to funding conflicts, products from stingless bees are only in the research stage, as the industrial sector is still finding obstacles and a lack of confidence to invest in these projects. Furthermore, according to Lee, the production of stingless bee honey in Malaysia alone is expected to have an annual sales rise from MYR 33.6 million to MYR 33.6 billion in the near future [12]. Hence, in exploring the potential of stingless bee products, government and non-government organisations need to play a role in supporting production of stingless bee products and encourage scientists to conduct more studies aimed at discovering their potential.

6. Conclusions

This review presents a comprehensive study of stingless bee products and the variety of their benefits. Throughout this review, the beneficial values of stingless bee products are revealed by their unique properties, i.e., antioxidant, antimicrobial, and anticancer, which are superior to common European honeybee honey. The enormous amount of reported chemical compounds found in propolis are also highlighted, and play an important factor due to its antioxidant and antimicrobial properties. Common pathogens and fungi that are known to cause harm to humans and food products have been proven to be sensitive against most stingless bee honey. Several novel approaches using stingless bee honey in handling cancer had promising breakthroughs. Thus, stingless bee products, especially honey, have the potential to revolutionise many industries and indirectly promote a healthier lifestyle for consumers.

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