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Quality, Safety, and Functional Properties of Bee Honey: A review

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ABSTRACT

This comprehensive review aimed to investigate the quality, safety, and functional properties of bee honey, an unprocessed and natural food product recognized for its dual role as a sweetener and medicinal substance. Due to the influence of diverse floral sources from various geographical regions, bee honey has a notable increase in global consumption. However, its growing popularity highlights concerns about potential adulteration, prompting the establishment of stringent safety and quality parameters by regulatory authorities. The major objective of this review was to provide a thorough examination of common adulterants in bee honey and to present effective detection methods. Unchecked adulteration causes inherent health risks, including elevated blood sugar levels, contributing to complications such as abdominal obesity, diabetes, obesity, and increased blood lipids and hypertension. Adverse effects of honey adulteration can be mainly observed in the liver, and secondary impacts on the heart, kidney, and brain. Despite the challenges due to adulteration, bee honey provides essential functional properties, particularly its antioxidant and antimicrobial activities. Phenolic compounds, reducing sugars, and amino acids in honey give its antioxidative capabilities, addressing intracellular oxidative damage associated with aging, neurodegenerative diseases, and apoptosis. The phenolic compounds also show efficacy against spoilage and pathogenic microorganisms. Enzymes in bee honey enhance its antimicrobial potential, and the inclusion of lactic acid bacteria generates various bioactive compounds, acting as prebiotics to enhance gut health. The insight of this review revealed the need of strong quality and safety standards in the bee honey industry. Moreover, the functional attributes of bee honey are emphasized its positive impact on human health and overall well-being, reinforcing the importance of safeguarding the integrity of this natural product.

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INTRODUCTION

Bee honey is the world's oldest natural sweetener. It has been recently gained global market favor, which recognized for its nutritional and therapeutic properties. According to the Codex Alimentarius Commission, pure honey is a natural sweet substance produced by honey bees, emphasizing a complex process from collecting nectar to ripening in honeycombs (Codex, 2001). Apart from its sweetness, honey serves as a nutraceutical agent and a natural functional food (Tahir et al., 2019). The honey processing chain, illustrated in Figure 1 involves critical steps for ensuring high-quality honey, with contributors to quality degradation including high-temperature heating, moisture content, adulteration, packaging, and storage conditions.

Apiculture plays a vital role in rural economies, with the honey market expanding globally. China leads in honey production, accounting for 27% of the global market in 2016, while India boasts the highest number of beehives (Teferi, 2018). Honey, composed of glucose, fructose, maltose, and sucrose, also contains minor constituents such as proteins, enzymes, amino

acids, organic acids, vitamins, and various bioactive compounds, contributing to its diverse applications and health benefits (Cornara et al., 2017). Its applications range from food products to pharmaceuticals, and cosmetics, demonstrating antibacterial, anti-inflammatory, and antioxidant activities (Cornara et al., 2017).

However, the premium price and demand for honey lead to potential adulteration challenges, compromising overall product quality (Ismail, 2019). As there are less availability of standards, market infrastructure, technical know-how, and analytical methods contribute to adulteration issues (Teferi, 2018). Identification of pure honey and ensuring authenticity are crucial aspects (He et al., 2020). The aim of this review was to reveal the physicochemical characteristics, stability, and functional properties of honey. It has been strengthening with analytical methods for authenticating honey and detecting adulterants. It emphasizes the therapeutic benefits of its bioactive compounds. The goal was to inspire further research and development in honey authentication technologies and the creation of functional honey products for enhanced health benefits.

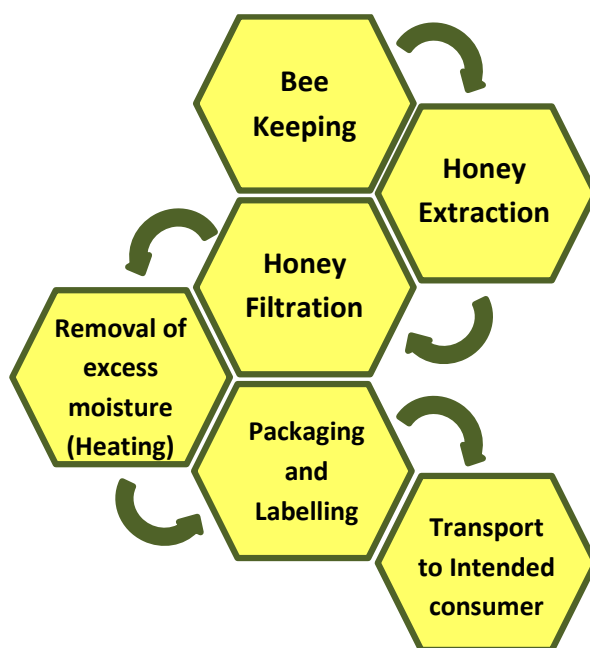


Figure 1. Overview of the processing chain for pure natural bee honey

RESULTS & DISCUSSION

Overview of quality and safety criteria for pure honey

Pure bee honey owns excellent sensory, physicochemical, and microbiological attributes, pivotal elements influencing consumer acceptance, and the triumph of honey-based food products. These quality benchmarks bear the imprint of both natural and anthropogenic influences, presenting variations rooted in botanical and geographical origins (Solayman et al., 2016).

Sensory evaluation of pure honey

Referring the traditional French methods for honey analysis, a standardized framework has been evolved which is led by the International Honey Commission of Apimondia (IHC) and the U.S. National Honey Board in 2002 (Siddiqui et al., 2017). Aligning with ISO standards, it covers analytical and affective dimensions. Trained panels focus on identifying botanical origins, detecting defects, and assessing attributes like fermentation. Affective sensory measurements involve larger panels, providing insights into consumer preferences. Characteristics are evaluated across visual attributes, aroma, taste, and texture. Honey aroma is influenced by volatile compositions,

and taste encompasses sweetness, acidity, bitterness, sharpness, and aftertaste. Texture attributes like smoothness, meltability, viscosity, sandiness, and adhesiveness are also assessed (Siddiqui et al., 2017).

Sensory analysis ensures honey quality, assesses acceptability, and identifies faults. Traditional tests, conducted by trained individuals or consumers, offer reliable results.

Emerging technologies, like electronic nose and electronic tongue, complement sensory evaluation, warranting future investigations into their efficacy in analyzing the sensory quality of bee honey (Siddiqui et al., 2017).

Physicochemical quality and safety of pure honey

As depicted in Table 1, comprehensive international standards, established by the Codex Alimentarius Commission and the European Community, govern the physicochemical quality of bee honey. The European Community ensures the quality of organic honey without chemical substances. Local standards from honey-producing nations supplement these guidelines. Key parameters include total sugar, moisture, water-insoluble solids, electrical conductivity, free acid, diastase activity, and hydroxymethylfurfural (HMF) (Codex, 2001).

Table 1. Summary of international physicochemical quality standards for bee honey

Physicochemical Quality Parameter	Codex standard [†] / European communities Council [‡]
Moisture (%)	<20
Fructose and glucose content (sum) (g/100 g)	>60
Sucrose (g/100 g)	<5
Water-insoluble solids content (g/100 g)	<0.1
Electrical conductivity (mS/cm)	<0.8
Free acid (mEq/kg)	<50
Diastase activity (Schade scale)	>8
Hydroxymethylfurfural content mg/kg	<40

[†] A collection of internationally adopted food standards and related texts

[‡] An essential decision maker, negotiates and adopts legislative acts

The research underscores variations due to botanical feeding sources, urging exploration in diverse locations. Producers often label shelf life without considering physicochemical quality, prompting the need for models estimating shelf life based on characteristics (Fallico et al., 2009).

Further research should establish certification marks and enhance assessment criteria for honey from diverse locations. Note that the criteria provided pertaining to blossom or nectar honey. Monofloral varieties, such as lavender, red gum, and leatherwood, may have slightly different criteria, which can be referenced in their respective standards.

Microbial quality and safety of pure honey

Physicochemical properties of honey such as low water activity, pH, sugar concentration, and antibacterial compounds, create an inhospitable environment for microorganisms (Manyi-Loh et al., 2011). Despite maintaining a low microbial load, honey can be affected by primary sources like pollen, honeybee digestive tracts, and secondary sources such as processing and storage (Adadi and Obeng, 2017).

Increased microbial load can reduce shelf life and pose health risks. Managing secondary sources through good practices is crucial. Common microorganisms include yeast responsible for fermenting honey and indicators like *Escherichia coli* and spore-forming bacteria (Adadi and Obeng, 2017).

To ensure honey quality, the World Trade Organization recommends Codex Alimentarius standards (2001). These standards specify microbial and hygienic qualities, emphasizing free from microorganisms and health-hazardous substances (Codex, 2001).

Researchers use ISO/IEC 17025 and ISO 16140-1:2016 methods for microbial assays, assessing aerobes, coliforms, *E. coli*, and fungi in honey (Adjalooc et al., 2017). However, uncertainties about local standards call for global health authorities to introduce legislation, standards, and laws to ensure

microbial safety in honey production, handling, and analysis.

Adulteration and health risks associated with bee honey

The practice of adulterating bee honey, driven by market shortages and commercial demands, raises significant concerns regarding its impact on human health. Commonly used adulterants such as table sugar, sucrose syrup, and high fructose corn syrup pose substantial risks, contributing to chronic diseases like obesity, diabetes, and severe organ toxicity. Experimental data, as highlighted by Goldstein (2015), underscores the direct association between the long-term consumption of adulterated bee honey and adverse health outcomes.

Long-term animal studies conducted on rats to evaluate the effects of adulterated bee honey reveal disturbing findings. Treatment-related deaths, coupled with behavioral changes such as aggressiveness and excessive drinking of water, are observed in animals. Physical manifestations, including grooming tachycardia, thinning hair, heavy breathing, and lethargy, further emphasize. Notably, rats exposed to adulterated honey exhibit increased fat pads, triglyceride levels, cholesterol, glucose levels, and BMI, indicative of a propensity for obesity, hyperglycemia, and diabetes (Ismail et al., 2018).

Experimental results show severe toxicity, evident in a significant increase in liver and kidney marker enzymes, such as serum aspartate aminotransferase (AST) and alanine aminotransferase (ALT). Toxic consequences associated with the consumption of adulterated bee honey include markers like total bilirubin, total protein levels, creatinine levels, and abnormalities in organ weight (de Barros Pereira, 2014).

While conclusive evidence on the negative effects of adulterated honey is lacking, the presence of toxins raises alarms regarding potential heart problems, chest pain, and low blood pressure. Uncertainties persist regarding the safety of bee honey consumption, especially

Table 2. Advanced detection methods for indirect adulteration of honey

Type of adulterant fed to honey bees	Purpose of adulterating	Physicochemical changes after the adulteration	Detection method	Reference
Industrial Sugar Syrups	To improve the sugar composition and sweetness of honey	Sugar composition has been changed	High Performance Anion Exchange Chromatography with Pulsed Amperometric	(Zábrodská and Vorlová, 2015)
High-Fructose Corn Syrup (HFCS)	To improve the sugar composition and sweetness of honey	Higher levels of Fructosylfructose were detected in honey made by bees fed with FCS. Fructosylfructose already contains in pure bee honey with lower levels.	Detection (HPAEC-PAD) Gas Chromatography Coupled with Mass Spectrometry (GC-MS)	(Zábrodská and Vorlová, 2015)
Corn Syrups with High Fructose-85 (HFC-85%), Moderate Fructose-55 (HFC-55%),	To improve the sugar composition and sweetness of honey	Carbon isotope ratios. ($\delta^{13}\text{C}$ values) for honey sugars and proteins	Elemental Analyzer– Isotope Ratio Mass Spectrometry (EA–IRMS)	(Guler <i>et al.</i> , 2014)

for breastfeeding and pregnant women in medicinal amounts, with a recognized risk of botulism poisoning in infants below 12 months exposed to adulterated honey (Aureli, et al., 2002). Additionally, the inclusion of adulterated sugar syrups in honey contributes to tooth decay, though comprehensive experimental data on these negative effects remains limited. The intertwined issues of adulteration and associated health risks underscore the urgency for further research and stringent measures to safeguard the integrity and safety of bee honey in the market.

Analytical methods for detecting honey adulteration

Honey adulteration poses a complex challenge globally, significantly impacting economies. Commercial honey adulteration can be categorized as direct, indirect, and blending (Fakhlaei et al., 2020). Direct adulteration involves adding foreign substances directly into honey. Often, honey is adulterated with substances like sugar, molasses, water, banana, wheat, maize syrup, or flour (Mehryar and Esmaili, 2011). Occasionally, harmful substances such as antibiotics, colorings, and hydroxymethylfurfural (HMF) are used as adulterants for bee honey. Indirect adulteration occurs when honey bees are fed industrial sugars during the stage when broods become naturally available. Detecting these types of indirect adulterations is challenging through laboratory-scale analysis, as carbohydrate profiles can be synthesized to mimic naturally available carbohydrates present in true honey (Zábrodská and Vorlová, 2015). The blending method involves mixing high-quality (pure and rare) honey with cheaper, lower-quality honey. Rape honey is the most abundant and cheap honey used for blending (Fakhlaei et al., 2020).

Tables 2 and 3 provide a comprehensive overview of advanced detection methods for both indirect and direct honey adulteration, including the type of adulterant fed to honey bees, the purpose of adulterating, physicochemical changes post-adulteration, and the corresponding detection methods.

Functional properties of bee honey

Bee honey, crafted by industrious honey bees, serves not only as a delectable natural sweetener but also boasts a myriad of functional properties integral to its nutritional and therapeutic value. Illustrated in Figure 2, honey transcends its conventional sweetening role, embracing a spectrum of functionalities. These encompass potent antioxidant activity, anti-inflammatory effects, remarkable wound-healing properties, robust antimicrobial capabilities, efficacy as a cough suppressant, promotion of gastrointestinal health, potential cardiometabolic benefits, and emerging indications of neurological effects. This multifaceted profile positions honey as a versatile ingredient, capturing the fascination of scientific inquiry and elevating its status beyond mere sweetness.

Health benefits of bee honey

Antioxidant activity of bee honey

Oxidative agents, like free radicals, pose a threat to cell defense systems, causing damage to biomolecules in the human body (Nagai et al., 2001). Honey, rich in enzymatic (catalase, glucose oxidase, peroxides) and non-enzymatic (ascorbic acid, proteins, flavonoids, phenolic acids) antioxidants acts as a protective shield against oxidative damage (Viuda-Martos et al., 2008).

The mechanism through which honey antioxidants operate involves inhibiting free radical formation catalyzed by metal ions, such as iron and copper. This inhibition prevents undesirable characteristics like flavor and odor changes, color loss, and shelf-life reduction in food materials (Viuda-Martos et al., 2008). It's crucial to consider various factors affecting honey's antioxidant capacity, including the flower source of nectar, seasonal variations, environmental conditions, genetic factors, and processing methods (Viuda-Martos et al., 2008).

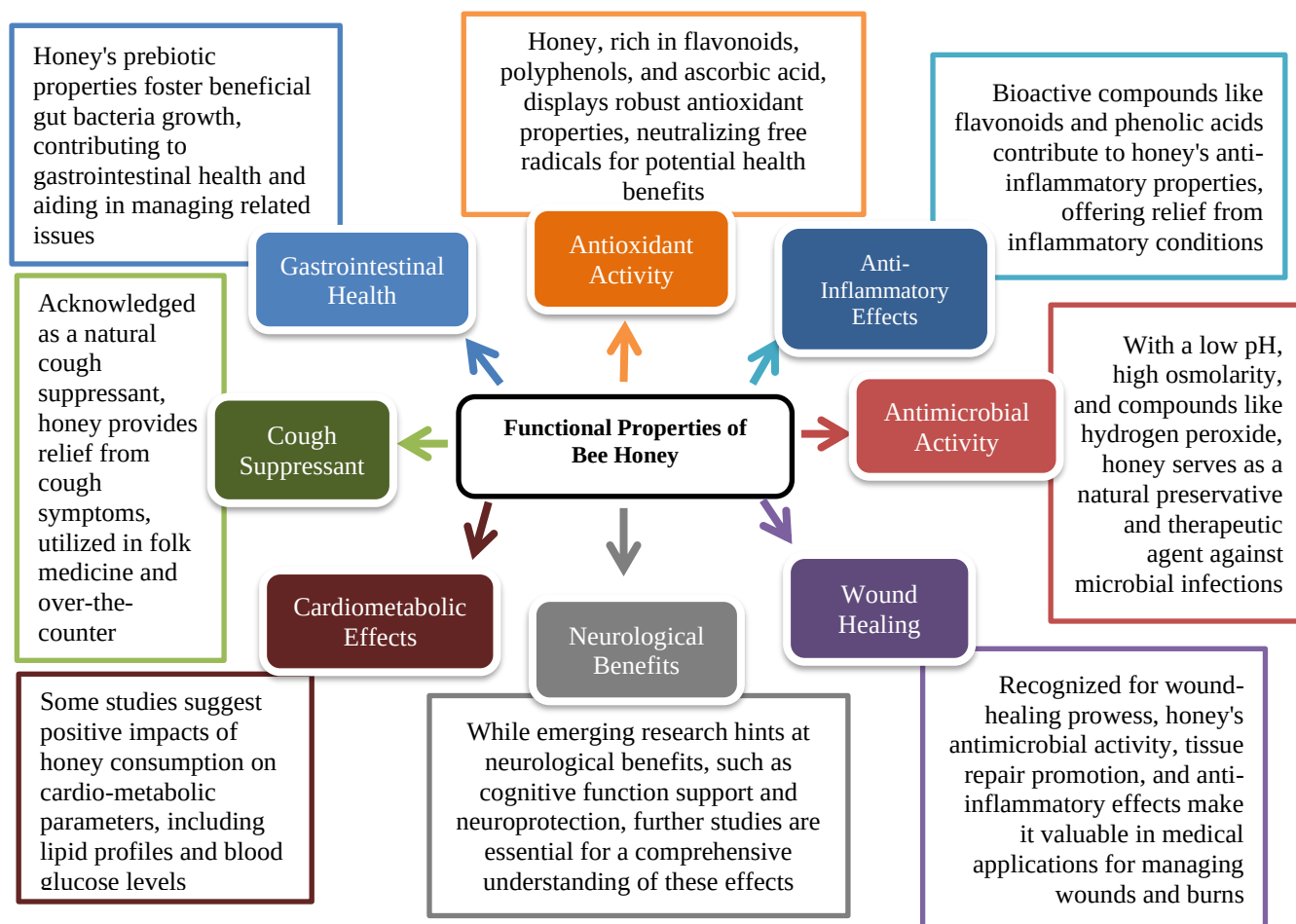


Figure 2. Functional properties of bee honey

Neurological benefits of bee honey

Oxidative stress, a common consequence of insults to neuron cell integrity, is linked to aging, neuroinflammation, and exposure to neurotoxins (Mijanur et al., 2014). Aging contributes to cognitive decline and elevates the risk of neurodegenerative disorders due to accumulated oxidative damage and a compromised antioxidant defense system. Bee honey, renowned for its anti-inflammatory, antiacetylcholinesterase (AChE), and antioxidant properties, hence become a focal point in therapeutic studies exploring cognitive function (Zaidi, 2019).

Studies have exhibited the positive impact of honey on the brain, revealing heightened antioxidant levels in both plasma and brain tissues following honey ingestion. Neurotrophins present in honey, such as brain-derived neurotrophic factors, contribute to

enhanced spatial memory, stress response, and the alleviation of anxiety and depressive behaviors in animal studies (Miranda, 2019). Additionally, polyphenols like caffeic, ellagic, and chlorogenic acids found in honey exhibit antioxidant effects, diminishing the generation of reactive oxygen species (ROS) and providing neuroprotection against memory impairment (Kwon et al., 2010).

Honey's neuropharmacological effects, mediated through various central mechanisms, contribute to anxiety reduction. Chrysin, a flavonoid in honey, is identified as an anxiolytic with potential cognitive and learning capacity benefits (Mijanur et al., 2014). Animal studies suggest that varying concentrations of honey can positively influence anxiety levels.

Although the direct impact of honey on brain cells is not fully elucidated, accumulat

Table 3. Advanced detection methods for direct adulteration of honey

Type of adulterant	Purpose of adulterating	Characteristic/Compound to be measured	Detection method	Reference
Adulteration with C4 sugars (corn and cane sugar)	To improve the sugar profile and sweetness of honey	$^{13}\text{C}/^{12}\text{C}$ Carbon Isotope Ratio	Stable Carbon Isotope Ratio Analysis (SCIRI)	(Zábrodská and Vorlová, 2015)
High Fructose Corn Syrup (HFCS)	To increase the fructose content. Also, it has a detrimental effect on the colony (pH and HMF content) and the quality of the resulting honey	Polysaccharide profiles	High-Performance Anion Exchange Chromatography with Pulsed Amperometric Detection.	(Zábrodská and Vorlová, 2015)
Addition of High Fructose Corn Syrup at after-storage period	Improve the sugar profile during the storage period	Volatile compounds	Mass Spectrometry (SIFT-MS) and Soft Independent Modelling by Class Analogy (SIMCA)	(Zábrodská and Vorlová, 2015)
Maltose Syrup (MS)	To improve the sugar profile and sweetness of honey	Maltose impurities	Raman Spectroscopy	(Ayton et al., 2019)
High Fructose Corn Syrup (HFCS) mixed with Invert Sugar Syrup.	To improve the sugar profile and sweetness of honey	Difructose Anhydride (DFAS)	Gas Chromatography coupled with Mass Spectrometry (GC-MS)	(Zábrodská and Vorlová, 2015)
Added sugars such as glucose, fructose, sucrose, and corn syrup	To improve the sugar profile and sweetness of honey	Added sugar content	Combination of Infrared Fourier Transform Spectroscopy	(Zábrodská and Vorlová, 2015)

Table 3. Cont.

Type of adulterant	Purpose of adulterating	Characteristic/Compound to be measured	Detection method	Reference
Mixes of Corn Syrup (CS) and High Fructose Corn Syrups (HFCS)	To improve the sugar profile and sweetness of honey	Oligosaccharides profile	High-performance anion Exchange Chromatography with Pulsed Amperometric Detection (HPAEC-PAD)	(Ayton et al., 2019)
Cane Sugar	To improve the sugar profile and sweetness of honey	Parenchymal cells, Round cells and Epidermal stem cells	Polarized Light Microscopy	(Zábrodská and Vorlová, 2015)
Cane Sugar and Beet Sugar Syrups	To improve the sugar profile and sweetness of honey	Added cane and beet sugar	Fourier Transform Raman Spectroscopy Electronic Nose (e-nose) and Electronic Tongue (e-tongue)	(Zábrodská and Vorlová, 2015)
Rice Syrup	To improve the sugar profile and sweetness of honey	2-acetyl-3-glucopyranoside (AFGP)	Liquid Chromatography Tandem Mass Spectrometry	(Zábrodská and Vorlová, 2015)
Invert Sugar from Corn and Wheat	To improve the sugar profile and sweetness of honey	Exogenous Gamma-amylases (Glucoamylase, Amyloglucosidase)	Liquid Chromatography coupled to Isotope Ratio Mass Spectrometry (LC-IRMS)	(Zábrodská and Vorlová, 2015)
Rice Syrup	To improve the sugar profile and sweetness of honey	2-acetylfuran-3-glucopyranoside (AFGP)	High Performance Liquid Chromatography with Diode Array Detection (HPLC-DAD)	(Zábrodská and Vorlová, 2015)

Table 3. Cont.

Type of adulterant	Purpose of adulterating	Characteristic/Compound to be measured	Detection method	Reference
		Electrochemical cells by detecting electrochemical signals in cyclic voltammetry	Electrochemical Sensor along with Chemometric methods	(Zábrodská and Vorlová, 2015)
Isoglucose Syrups	To improve the sugar profile and sweetness of honey	¹³ C isotope ratios of individual sugars	Liquid Chromatography and Isotope Ratio Mass Spectrometry (HPLC-IRMS)	(Zábrodská and Vorlová, 2015)
Industrial Sugar Syrups	To improve the sugar profile and sweetness of honey	Thermal and thermochemical properties such as Glass transition temperature (T _g), Melting enthalpy (ΔH _{fus}), and the Change in heat capacity (ΔC _p)	Differential Scanning Calorimetry (DSC)	(Zábrodská and Vorlová, 2015)
Synthetic Sugar	To improve the sugar profile and sweetness of honey	Glucose, Fructose, Sucrose, and Maltose	Fourier Transform Infrared Spectroscopy (FTIR) in combination with chemometrics	(Ayton et al., 2019)
Individual Sugars	To improve the sugar profile and sweetness of honey	Fructose and Glucose	Ultraviolet-visible spectroscopy (UV-VIS)	(Zábrodská and Vorlová, 2015)
Acacia Honey adulterated with Fructose	To improve the sugar profile and sweetness of honey	Dielectric Constant	High-Performance Thin Layer Chromatography	(Zábrodská and Vorlová, 2015)

Table 3. Cont.

Type of adulterant	Purpose of adulterating	Characteristic/ Compound to be measured	Detection method	Reference
High Fructose Inulin Syrups (HFIS)	To improve the sugar profile and sweetness of honey	Inulotriose (Marker)	Gas Chromatography Coupled with Mass Spectrometry (GC-MS)	(Zábrodská and Vorlová, 2015)
Sulphite Ammonia Caramel	To improve the color of honey	Color intensity	Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS)	(Zábrodská and Vorlová, 2015)

evidence emphasizes honey's potential therapeutic role in preserving brain function during aging and addressing conditions associated with oxidative stress, inflammation, and neurodegeneration (Azman & Zakaria, 2019).

Tumor-fighting potential of bee honey

Bee honey emerges as a reservoir of diverse compounds, including flavonoids, terpenoids, and steroids, known for their potent pharmacological effects. These components, particularly celebrated for their antioxidant prowess, demonstrate promising capabilities against cancers and carcinogenic agents. Extensive research delves into the therapeutic promise of bee honey across various cancers, encompassing breast, colorectal, liver, renal, and leukemia (Bogdanov, 2016).

Noteworthy findings showcase the antitumor properties of specific honey variants like Tualang and Manuka against breast cancer cell lines. Meanwhile, Greek honey exhibits a nuanced impact on estrogenic activity and cell viability in breast MCF-7 cancer cells, displaying antiestrogenic effects at lower concentrations and estrogenic effects at higher concentrations (Tsiapara et al., 2009). Further, honey demonstrates antiproliferative potential against colon cancer cells (HCT-15 and HT-29), as evidenced by 3-(4, 5-dimethylthiazol-2-yl)-2, 5-diphenyl tetrazolium bromide (MTT) assay results. Studies probing bladder cancer reveal bee honey's effectiveness in inhibiting the growth of diverse bladder cancer cell lines (T24, RT4, 253J, and MBT-2), whether administered intralesionally or orally in MBT-2 bladder cancer implantation mice models (Erejuwa et al., 2014).

The multifaceted mechanisms behind bee honey's anti-tumor activity encompass cell cycle arrest, activation of the mitochondrial pathway, induction of mitochondrial outer membrane permeabilization, apoptosis initiation, inhibition of Tumor Necrosis Factor (TNF), modulation of oxidative stress, anti-inflammatory action, immuno-modulation, modulation of insulin signaling, inhibition of

angiogenesis, and anti-mutagenic effects (Premratanachai & Chanchao, 2014). This collective evidence underscores the potential of bee honey as a valuable player in the quest against various forms of cancer.

Anti-inflammatory action

Inflammation, often triggered by infection or injury, can lead to tissue damage if the response becomes excessive or prolonged. Key contributors to the inflammatory process include pro-inflammatory enzymes, cytokines, and compounds like eicosanoids, along with the enzymatic breakdown of tissues. Cyclooxygenase-2 (COX-2) a major player in inflammation which plays a crucial role, in this process by transforming arachidonic acid into prostaglandin. Conversely, cyclooxygenase-1 (COX-1) helps to regulate homeostasis (Ricciotti & FitzGerald, 2011).

Galangin is a flavonoid in bee honey that contributes for the anti-inflammatory effects in various manner such as inhibiting COX and lipo-oxygenase activity while reducing polygalacturonase action, and limiting the expression of the inducible isoform of COX-2. Caffeic acid phenethyl ester (CAPE) is a natural compound in bee honey, further contributes to the suppression of COX-1 and COX-2 activity by inhibiting arachidonic acid release, while inhibiting the genic expression of COX-2 (Viuda-Martos et al., 2008). Insights of the review underscore the potential of bee honey and its bioactive components in modulating essential enzymes involved in the inflammatory response, offering promising anti-inflammatory benefits.

Gastrointestinal health and bee honey

Bee honey has a beneficial effect on gastrointestinal health. Its prebiotic properties support the growth of beneficial gut bacteria while maintaining a healthy gut microbiota (Erejuwa et al., 2014; Alvarez-Suarez et al., 2010). Essential probiotics such as Bifidobacteria and Lactobacillus are proliferated with the prebiotic effect. are crucial

for maintaining gut balance and digestive well-being (Erejuwa et al., 2014).

Furthermore, bee honey as a potential natural preservative and therapeutic agent against microbial infections in the digestive system due to its antimicrobial activity. It is derived from its low pH, high osmolarity, and compounds like hydrogen peroxide (Alvarez-Suarez et al., 2010).

Bee honey gives a delightful taste into the diet as a natural sweetener and also has potential advantages for promoting gastrointestinal well-being. The intricate interplay between honey's bioactive components and the complex digestive system environment underscores the need for continued exploration in the field (Erejuwa et al., 2014; Alvarez-Suarez et al., 2010).

Moreover, probiotic activity against pathogens is enhanced by the symbiotic relationship between prebiotic oligosaccharides and antibacterial compounds in honey. This impact extends to an increased viable cell count, enhanced probiotic persistence, and a synergistic antibacterial effect when combined with bovine lactoferrin. Notably, specific probiotic strains in honey such as *Lactobacillus reuteri* revealed by the studies, showcase significant probiotic capabilities (Mohan et al., 2017). These findings highlight bee honey's potential as both a prebiotic substrate and a source of probiotic strains, contributing to gastrointestinal health.

Wound healing properties of bee honey

Bee honey has long been recognized for its remarkable wound-healing properties, making it a valuable asset in traditional and contemporary medicine. Several bioactive components contribute to its effectiveness in promoting wound healing. The wound-healing properties of bee honey encompass a multifaceted approach, involving antimicrobial, anti-inflammatory, antioxidant, and tissue repair mechanisms.

Honey's broad-spectrum antimicrobial activity is attributed to its low pH, high osmolarity, and

the presence of compounds like hydrogen peroxide (Alvarez-Suarez et al., 2010). Bioactive compounds such as flavonoids and phenolic acids in honey contribute to its anti-inflammatory effects, aiding in the reduction of inflammation at the wound site (Erejuwa et al., 2012). Honey promotes tissue repair through its ability to stimulate fibroblasts, enhance collagen deposition, and accelerate the overall healing process (Alvarez-Suarez et al., 2010). The antioxidant properties of honey, attributed to compounds like flavonoids, protect against oxidative stress, facilitating an optimal environment for wound healing (Alvarez-Suarez et al., 2010). Honey's ability to create an unfavorable environment for microbial growth helps prevent infections in wounds, contributing to a cleaner healing process. The hygroscopic nature of honey maintains a moist environment at the wound site, promoting optimal conditions for tissue regeneration and minimizing scarring. Clinical studies highlighted the successful use of honey in wound management, demonstrating its efficacy in various wound types, including burns, ulcers, and surgical wounds (Alvarez-Suarez et al., 2010).

Antimicrobial properties of bee honey

Bee honey possesses both indirect and direct antimicrobial activities. Indirectly, it relies on immune activation, anti-inflammatory action, and prebiotic content. Directly, it exhibits bacteriostatic and bactericidal effects, especially against gram-positive bacteria, attributed to osmotic dehydration and hydrogen peroxide content (Manyi-loh et al., 2011). The osmotic dehydration, driven by high sugar-water affinity, limits free water crucial for microbial growth.

Hydrogen peroxide, a byproduct of glucose oxidation, generates free radicals with antibacterial properties, although it can be easily destroyed. Notably, some honey types maintain antimicrobial properties even in the presence of catalase, possibly influenced by flower source and honeybee origin. Natural acidity and lysozyme further contribute to bee honey's antibacterial capacity (S. Bogdanov et al., 1997).

Compounds like pinocembrin, galangin, caffeic acid, and phenethyl ester inhibit bacterial RNA polymerase, while flavonoids such as galangin degrade bacterial cytoplasmic membranes. Quercetin present in bee honey inhibits bacterial ATP synthesis (Viuda-Martos et al., 2008).

Limited studies explored bee honey's antiviral properties, with significant effects reported against rubella and herpes simplex viruses (HIV). Flavonoids like galangin, quercetin, and rutin in honey contribute to antiviral activity against various viruses, including HSV and coxsackie B virus (Miguel et al., 2017). Royal jelly's 10-Hydroxy-2-Decenoic acid stimulates white blood cells to combat viruses like HSV and hepatitis. Propolis and its derivatives hinder viral multiplication, exhibiting virucidal action against several viruses (Viuda-Martos et al., 2008). Flavonoids in honey and propolis inhibit viral transcription and replication, showcasing diverse antiviral capabilities.

Cardio metabolic effects of bee honey

Study findings indicate antioxidants and bioactive compounds may contribute potential cardio-metabolic effects of bee honey. It gives benefits related to cardiovascular health and metabolic parameters. These compounds may help to reduce oxidative stress and inflammation, contributing to overall heart health. Studies have suggested honey shows a positive influence on blood lipid and honey consumption may lead to a decrease in total cholesterol, low-density lipoprotein (LDL) cholesterol, and triglyceride levels while increasing high-density lipoprotein (HDL) cholesterol levels (Erejuwa et al., 2012).

Some studies suggested a hypotensive (blood pressure-lowering) effect of honey. It could be useful for those with hypertension because of its vasodilatory and anti-inflammatory effects (Al-Waili et al., 2003). Honey consumption improves glucose metabolism. It whichs might have a possible good effect on glycemic control thus this could be a potential option for diabetic patients. The bioactive compounds in honey such as phenolic acids, have been investigated

for their anti-diabetic properties. These compounds may contribute to improved insulin sensitivity and reduced oxidative stress (Alvarez-Suarez et al., 2010).

Platelets are crucial for maintaining haemostasis, preventing bleeding, and playing a role in processes like thrombosis and inflammation. However, platelet aggregation is a key factor in cardiovascular diseases (Jackson, 2007). Bee honey has demonstrated the ability to mitigate platelet aggregation through various mechanisms as described below.

Hydrogen peroxide inhibition

Studies suggest that bee honey, containing hydrogen peroxide, can inhibit platelet function when externally exposed. The presence of hydrogen peroxide in honey contributes to this inhibitory effect, influencing platelet aggregation (Ahmed et al., 2011).

ADP receptor antagonism

Honey appears to competitively antagonize ADP receptor-mediated platelet aggregation. This mechanism further contributes to the regulation of platelet activity, potentially reducing the risk of excessive aggregation associated with cardiovascular issues (Ahmed et al., 2011).

Cytokine regulation and reactive oxygen species (ROS) suppression

Activated platelets release cytokines that activate phagocytes. These activated phagocytes are associated with higher levels of free oxygen radicals. Antioxidant properties in honey, suppresses reactive oxygen species and influence platelet function indirectly, since free oxygen radicals can affect platelets through oxidative modification of low density lipoproteins (LDL) (Ahmed et al., 2011).

Bee honey exerts an inhibitory influence on platelet aggregation via hydrogen peroxide

Table 4. Process for the assessment of scientific support for claims on foods classification of most common health claims related to bee honey

“PASSCLAIM” category	Health Claim	Scientific Evidence	Responsible compound present in bee honey	Mode of Action	References
Diet-related cardiovascular disease	Reduce the risk of hypercholesterolemia	A human study investigating the impact of bee honey intake on cholesterol profiles revealed that individuals who consumed natural bee honey experienced a significant decrease in total cholesterol, low-density lipoprotein (LDL), and triglycerides in their serum and noted an improvement in high-density lipoprotein (HDL) levels over the 8-week experimental period.	Quercetin-3- β -D-glycoside, Vanillin, Luteolin and other phenolic compounds.	Bee honey's impact on cholesterol remains underexplored, but its positive associations with coronary vasodilation, clot prevention, and LDL-cholesterol protection are linked to its phenolic compounds. These compounds act by inhibiting the key enzyme HMG-CoA reductase, reducing total cholesterol, and modulating plasma LDL-C through upregulating LDL-receptor expression. Bee honey intake is also implicated in reducing CVD risk factors like C-reactive protein, prostaglandins, and homocysteine. Though the exact mechanisms require further study, these findings highlight bee honey's potential as a natural contributor to cardiovascular health.	(Al-waili et al., 2013; Thi et al., 2019)
	Reduce the risk of hypertension	An experiment examining the impact of bee honey on hypertensive rats revealed positive effects, indicating potential benefits of bee honey in mitigating hypertension in rats	Antioxidants	The antioxidants found in bee honey demonstrate the ability to decrease Malondialdehyde (MDA) levels, a byproduct of lipid peroxidation, and lower systolic blood pressure. The antioxidant activity of bee honey proves beneficial in alleviating kidney damage caused by hypertension in rats.	(Thi et al., 2019)

Table 4. Cont.

“PASSCLAIM” category	Health Claim	Scientific Evidence	Responsible compound present in bee honey	Mode of Action	References
				This protective effect is attributed to the upregulation of the expression of erythroid 2-related factor 2 (Nrf2), emphasizing the role of bee honey's antioxidants in mitigating oxidative stress and its potential impact on hypertension-related complications.	
Bone health and osteoporosis	Helps to recover from postmenopausal osteoporosis	A human study comparing the effects of honey and hormonal replacement therapy on postmenopausal osteoporosis concluded that there is no significant difference in bone density between the two treatment groups.	Antioxidants	Postmenopausal osteoporosis occurs due to oxidative stress induced by estrogen deficiency. Bee honey mitigates oxidative stress by enhancing the activities of indigenous antioxidant enzymes such as catalase (CAT) or glutathione peroxidase (GPX) and reducing the level of 4-hydroxynonenal (4-HNE).	(Kamaruzzaman et al., 2019)
Physical performance and fitness	Increase the physical performance	A study assessing the impact of bee honey and glucose on the performance of cyclists during a 65 km ride revealed that both honey and glucose led to increased performance among cyclists.	Fructose	Fructose is the predominant sugar source present in bee honey, providing a sustained energy boost and maintaining homeostasis as it absorbs slowly into the bloodstream.	(Abdulwahid et al., 2012)

Table 4. Cont.

“PASSCLAIM” category	Health Claim	Scientific Evidence	Responsible compound present in bee honey	Mode of Action	References
Body weight regulation, insulin sensitivity, and diabetes risk	Helps to avoid obesity	In an animal study investigating the correlation between bee honey intake and obesity, rats fed with bee honey showed a significant impact on weight gain and adiposity compared to rats consuming diets with equal energy densities. Additionally, another animal study indicated that rats fed with sucrose exhibited notably higher overall weight gain and body fat levels compared to rats fed with bee honey	Antioxidants and phenolic compounds	Compounds in bee honey contribute to delaying the postprandial ghrelin response and enhancing the total Peptide-YY (PYY) response, which reduces appetite. Additionally, bee honey blunts the glucose response and diminishes hunger and food intake. These effects highlight the potential of bee honey in regulating appetite-related mechanisms and glucose levels, offering potential benefits in managing postprandial responses.	(Al-waili et al., 2013)
	Lower the glycemic index	A human study aimed at determining the effect of bee honey and a reference food sample on the glycemic index found that individuals who consumed bee honey exhibited a significantly lower glycemic index	Fructose	Fructose, the primary carbohydrate in bee honey, has been studied for its impact on the digestive process. Research suggests that fructose consumption may extend gastric emptying, thereby delaying intestinal absorption. This finding highlights the potential influence of bee honey on the	(Al-waili et al., 2013)

Table 4. Cont.

“PASSCLAIM” category	Health Claim	Scientific Evidence	Responsible compound present in bee honey	Mode of Action	References
		compared to those who consumed the reference food sample		digestive timeline, providing insights into its physiological effects on the gastrointestinal system	
	Reduce the risk of diabetes mellitus	In a human experiment investigating the hyperglycemic effects of glucose, sucrose, and honey	Fructose, disaccharides present in bee honey such as Palatinose	Bee honey reduces the production of reactive oxygen species (ROS), decreases glucose-induced lipid peroxidation, and increases insulin	(Al-waili et al., 2013; Thi et al., 2019)
		on diabetes mellitus patients, it was observed that bee honey could reduce postprandial glycemic response in these patients. Another human study comparing the effects of bee honey and dextrose on plasma glucose levels (PGL) demonstrated a significantly lower rise in PGL in individuals who consumed bee honey.	(Isomaltulose) and Phenolic compounds	content. As a result, bee honey enhances cell viability under hyperglycemic conditions. These findings suggest potential therapeutic effects of bee honey in mitigating oxidative stress and supporting cellular health in the context of diabetes mellitus.	

Table 4. Cont.

“PASSCLAIM” category	Health Claim	Scientific Evidence	Responsible compound present in bee honey	Mode of Action	References
Diet-related cancer	Reduce the risk of breast cancer.	Experiments investigating the anticancer effect of bee honey on human breast cancer cell lines revealed significant positive results. In another experiment involving rats with breast cancers induced by 12-dimethylbenz(a)anthracene (DMBA), those fed with bee honey exhibited fewer tumors and smaller tumor sizes compared to the control sample.	Flavonoids include chrysin, genistein, naringenin, and luteolin etc.	Bee honey exhibits anticancer effects through various mechanisms, including antagonizing estrogen activity, reducing mitochondrial membrane potential, stimulating the release of Tumor Necrosis Factor-alpha (TNF-alpha), inhibiting the oxidation of lipoproteins and cell proliferation, and inducing apoptosis and cell cycle arrest.	(Erejuwa et al., 2014)
	Reduce the risk of human liver cancer.	Treatment of human hepatocellular carcinoma (HepG2) cells with bee honey resulted in a significant reduction in the number of viable HepG2 cells and nitric oxide (NO) levels. Additionally, bee honey demonstrated the ability to enhance antioxidant levels in the cells.	Flavonoids and phenolic compounds	The anticancer compounds found in bee honey demonstrate multifaceted effects, inhibiting cell proliferation, suppressing angiogenesis, inducing apoptosis, and offering protection against mutagen-induced DNA damage.	(Erejuwa et al., 2014)

Table 4. Cont.

“PASSCLAIM” category	Health Claim	Scientific Evidence	Responsible compound present in bee honey	Mode of Action	References
	Reduce the risk of Colorectal Cancer	Multiple studies investigating the impact of bee honey on colon cancer cell lines HT 29 and HCT 15 have consistently demonstrated significant positive results, indicating a potential beneficial effect against cancer development	Flavonoids and phenolic compounds	Various mechanisms contribute to reducing the risk of colorectal cancers including inhibition of cell proliferation, induction of apoptosis, arresting the cell cycle, reduction in mitochondrial membrane potential, an increase of the generation of reactive oxygen species (ROS), depletion of intracellular non-protein thiols, induction of DNA damage, and suppression of inflammation.	(Erejuwa et al., 2014)
	Reduce the risk of other cancers including Human cervical cancer, oral carcinoma, osteosarcoma, human leukemia, etc	Honey has been found to inhibit carcinogenic pathways in different cancer cell lines, including cervical, mouth cells, and bone cancer cells.	Flavonoids and phenolic compounds	Various mechanisms contribute, including induction of apoptosis, disruption of mitochondrial membrane potential, and inhibition of cell proliferation	(Erejuwa et al., 2014)

Table 4. Cont.

“PASSCLAIM” category	Health Claim	Scientific Evidence	Responsible compound present in bee honey	Mode of Action	References
Mental state and performance	Improve the memory and intellect	In a human study involving postmenopausal women supplementing with bee honey, improvements in immediate memory were observed. Additionally, an animal study with rats fed bee honey demonstrated enhanced spatial memory after one year.	Antioxidants available in bee honey.	The morphology of memory-related brain areas can be improved by bee honey. Oxidants developed in the neuron system can damage proteins, lipids, and nucleotides, significantly affecting neuron function. This oxidative stress can be reduced by the antioxidants present in bee honey. Additionally, bee honey can increase the brain-derived neurotrophic factor (BDNF), a protein related to nerve growth. Consequently, bee honey can elevate acetylcholine (ACh) concentration and reduce acetylcholinesterase (AChE) concentration.	(Mijanur Rahman et al., 2014)
	Reduce anxiety	An animal study involving rats fed with varying concentrations of bee honey revealed that higher concentrations of honey have the potential to alleviate anxiety.	Antioxidants available in bee honey.	The neuropharmacological effects of bee honey contribute to reducing anxiety through mechanisms involving dopaminergic and nonopioid central pathways. These pathways include the voltage-gated sodium channel blocking hypothesis, activation of the noradrenergic inhibitory system, activation of serotonergic systems, and modulation of the GABAergic system.	(Mijanur Rahman et al., 2014)

Table 4. Cont.

“PASSCLAIM” category	Health Claim	Scientific Evidence	Responsible compound present in bee honey	Mode of Action	References
	Reduce the risk of depression	In a human experiment where individuals were supplemented with a tablespoon of bee honey daily, significant decreases were observed in scores related to depression, stress, and mood disturbances measured by Geriatric Depression Scale (GDS-R), Depression Anxiety Stress Scales (DASS), Profile of Depression Anxiety Stress Scales (DASS), Profile of Mood States (POMS), and Menopause Rating Scale (MRS) in comparison to the control group.	Antioxidants available in bee honey.	The induction of biochemical processes counteracts oxidative stress, reducing the impact of free radical activity. Bee honey provides protection to the highly vulnerable hippocampal CA1 region of the brain, minimizing degeneration of neuronal cells in response to oxidative insult. These findings emphasize the potential of bee honey as a natural agent to safeguard against oxidative damage in the brain, showcasing its neuroprotective properties.	(Ali & Hendawy, 2018; Mijanur Rahman et al., 2014)
Gut health, digestion, and immunity	Improve gut immunity through the symbiotic activity of bee honey.	In vitro incubation of Fecal bifidobacterium spp. demonstrated a significant increase in the total viable count of the probiotic strain with the addition of honey.	Probiotic bacteria (<i>Lactobacillus reuteri</i> , <i>Lactobacillus rhamnosus</i> , <i>Bifidobacterium lactis</i> etc.)	Probiotic bacteria can produce bioactive compounds, such as organic acids, free fatty acids, ethanol, benzoate, enzymes, hydrogen peroxide, bacteriocins, and	(Mohan et al., 2017)

Table 4. Cont.

“PASSCLAIM” category	Health Claim	Scientific Evidence	Responsible compound present in bee honey	Mode of Action	References
		In vitro, incubation and growth studies on four yogurt starters revealed that bee honey (5% w/v) supported the growth and activity of all bacterial species. Bee honey exhibited a prebiotic effect for four probiotic cultures (<i>B. lactis</i>, <i>L. rhamnosus</i>, <i>L. plantarum</i>, and <i>L. acidophilus</i>) in a detailed research study based on Australian honey varieties. An experiment utilizing bee honey as an encapsulant resulted in improved survivability of two probiotic <i>Bifidobacterium</i> strains in simulated gastrointestinal conditions.	Prebiotics (Dietary fibers, non-starch polysaccharides, resistant starch, oligosaccharides etc.)	antimicrobial peptides, to enhance the immune system	

inhibition, competitive antagonism of ADP receptor-mediated aggregation and inhibition of free oxygen radical release. These characteristics indicate that honey may play an essential role in affecting of platelet function, which have clear implications for cardiovascular health and thromboembolic processes.

Effects of bee honey on blood glucose level

There are several studies supporting the antidiabetic effects of bee honey in various aspects of diabetes management. A few of studies are shown that honey may influence on glycemic control. The use of honey as sweetener has been linked with lower postprandial blood glucose levels compared to other sweeteners (Erejuwa et al., 2012). Moreover, the glycemic index (GI) of Sri Lankan bee honey has been documented to be 53 ± 6.00 describing it as a low-GI food (Dahanayake et al., 2023).

Honey has demonstrated its ability to improve insulin sensitivity. Research indicates that regular honey intake may contribute to better insulin function, potentially benefiting individuals with insulin resistance or type 2 diabetes. Honey contains antioxidants such as flavonoids and phenolic acids with anti-inflammatory activities. Insulin resistance is frequently linked to chronic inflammation and honey's anti-inflammatory nature may enhance insulin sensitivity (Alvarez-Suarez et al. 2010)

Studies have shown that honey may protect pancreatic beta cells which produce insulin. This protective mechanism may help maintain adequate levels of insulin (Erejuwa et al., 2014). In fact, improved lipid profiles after honey consumption, such as lower total, low-density lipoprotein (LDL) cholesterol and triglycerides, and increase high-density lipoprotein (HDL) cholesterol, have been observed (Erejuwa et al., 2012).

Advanced glycation end-products (AGEs) play a role in diabetes-related complications. Honey has been shown to exhibit anti-glycation effects, potentially reducing the formation of

AGEs and mitigating their impact on various tissues (Kassim et al., 2010). While more research is needed, some studies explain its role in weight management which is also important in the management of diabetes. It is hypothesized that the satiety-inducing properties of honey could contribute to better appetite control and weight maintenance (Pittet et al., 2018). It's important to note that while these studies suggest potential antidiabetic effects of honey, individual responses may vary and its consumption is crucial due to its natural sugar content.

Efficacy of bee honey as a natural cough suppressant

Bee honey has been recognized for its efficacy as a natural cough suppressant, providing a soothing and beneficial remedy for respiratory discomfort. Honey's thick consistency and sticky nature coat the throat, offering relief from irritation and a soothing effect on the mucous membranes. Studies showed that honey can be effective in reducing cough frequency and severity, especially in the context of upper respiratory tract infections (Paul et al., 2007).

Honey's natural antimicrobial properties may contribute to its effectiveness in managing coughs associated with bacterial infections. Honey's natural antimicrobial properties may contribute to its effectiveness in managing coughs associated with bacterial infections (Mandal and Mandal, 2011). The antioxidant content of honey may play a role in reducing inflammation in the respiratory tract, contributing to its overall effectiveness as a cough suppressant (Mandal and Mandal, 2011).

Honey is a safe and viable alternative for managing cough symptoms in children over one year of age, providing a natural option without the potential side effects associated with certain over-the-counter cough medications (Oduwale et al., 2014). It is important to note that while honey can be a valuable component in alleviating cough symptoms, it should not be given to infants under one year of age due to the risk of botulism.

Health claims of bee honey

According to European Union regulation 1924/2006, various health claims can be made. These claims are categorized by means of the "Process for the Assessment of Scientific Support for Claims on Foods" (PASSCLAIM) project, in which the leading goals have been around the analysis of existing schemes the place scientific substantiation is assessed, the development of a generic instrument for assessing scientific support for health claims for foods, and setting out criteria for markers that can be used to see the relationships between diet and health (Asp et al., 2004). According to the PASSCLAIM project classification of the International Life Science Institute (ILSI), the claims are categorized into the following subject areas: Diet-related cardiovascular disease, Bone health and osteoporosis, Physical performance and fitness, Body weight regulation, insulin sensitivity, and diabetes risk, Diet-related cancer, Mental state and performance, and Gut health, digestion, and immunity (Asp et al., 2004).

Bee honey exhibits a broad spectrum of health claims as it consists of unique and distinct types of phenolic and flavonoid compounds, which have variable biological and clinical importance. As depicted in Table 4, the most common health claims related to bee honey include reducing the risk of hypercholesterolemia, reducing the risk of hypertension, helping to recover from postmenopausal osteoporosis, increasing physical performance, aiding in avoiding obesity, lowering the glycemic index, reducing the risk of diabetes mellitus, improving memory and intellect, reducing anxiety, reducing the risk of depression, reducing the risk of cancers, and improving the functions of the gastrointestinal system, among others. These health claims can be categorized according to the PASSCLAIM classification as mentioned above.

CONCLUSIONS

In conclusion, the consumption of bee honey holds promising therapeutic and nutritional benefits, showcasing antimicrobial, anticancer, and antioxidant properties that contribute to the

prevention of chronic diseases. While honey proves to be a healthier alternative to sugar, individuals, especially patients with diabetes mellitus on low-carb diets and certain vulnerable populations like pregnant women, should exercise with caution, particularly with raw honey. Emphasizing the importance of high-quality bee honey in moderate consumption is key to reaping noticeable health advantages. Recent research suggests that bee honey may offer neurological benefits, demonstrating potential roles in cognitive function and neuroprotection. Despite these promising findings, further investigations are essential to comprehensively understand the extent of these effects.

Looking ahead, addressing concerns related to honey adulteration is imperative. Current detection methods need expansion to cover a broader spectrum of quality indicators, prompting a revision of legislation to incorporate new insights into honey quality. Advanced analytical techniques for authenticity determination must be identified and endorsed by international organizations such as ISO and Codex. Implementing laboratory proficiency programs in ISO17025 accelerated laboratories ensures the reliability of results, supported by a comprehensive database for reference.

To bolster consumer confidence, a quality assurance program should be instituted, including logos verifying honey quality status. Annual market surveillance programs, incorporating quick and cost-effective techniques, can promote adherence to international standards and enhance consumer acceptance. Further research on the health benefits of honey is essential, delving into anxiolytic, antinociceptive, anticonvulsant, and antidepressant activities through expanded clinical trials. This extends to exploring functional properties in both natural and processed honey, necessitating ongoing studies to identify potential negative effects. In parallel, the safety of genetically modified bee honey warrants dedicated studies on physicochemical and functional properties, ensuring adherence to established guidelines and regulations. Continuous research and regulatory updates are crucial to optimizing the benefits of bee honey

while safeguarding its authenticity and safety in the market.

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All the Authors gave a significant contribution in the drafting of the paper.

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