REVIEW ARTICLE

Phytochemical Composition, Antioxidant, and Antimicrobial Potential of Honey: A Comprehensive Review

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Abstract

Honey is gaining recognition for its extensive therapeutic properties, attributed to its rich phytochemical composition shaped by the diverse flora in the area. This review delves into the antioxidant and antimicrobial characteristics of honey, emphasizing its potential applications in both traditional and modern medicine. The bioactive compounds found in honey, such as phenolic acids and flavonoids, play a critical role in alleviating oxidative stress and combating infections. By synthesizing existing research, this study seeks to validate the traditional medicinal uses of honey while encouraging its exploration as a natural health product. Furthermore, it aims to highlight the importance of investigating regional honey for its unique health benefits and its contributions to sustainable agricultural practices.

Highlights:

- This review explores the phytochemical profile of honey emphasizing its diverse chemical composition and potential health benefits.
- It examines the distinct antioxidant and antimicrobial properties associated with various floral sources of honey, showcasing the significance of local flora in enhancing honey's medicinal qualities.
- The review highlights the therapeutic potential of honey, including its role in modern medicine as a natural remedy for various ailments due to its bioactive compounds.
- Insights into the unique characteristics of honey underscore its value not only for local communities but also for broader applications in health and wellness.

Keywords: Honey, phytochemicals, antioxidant properties, antimicrobial properties, traditional medicine, natural health products.

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Introduction

Honey has been valued for centuries due to its nutritional and medicinal benefits. Its physical and chemical properties, such as viscosity, crystallization behavior, and antimicrobial activity, make it a versatile natural product. India, one of the largest honey producers, has a thriving apiculture industry, with major contributions from states like Uttar Pradesh, Punjab, Tamil Nadu, and West Bengal. Tables 1 and 2.

Understanding honey's characteristics and production trends is essential for assessing its quality and potential applications in the medicine and food industries. Honey has been revered for its wide array of therapeutic properties and holds an important role in both traditional and contemporary medicine. It is produced from the nectar of flowers through the enzymatic activities of bees, and its chemical composition varies significantly based on geographical location, climate, and the types of plants available (White *et al*., 2019; Bogdanov *et al*., 2008). The Terai region of Uttar Pradesh, India is particularly noted for its rich diversity of floral resources, which contribute to the distinctive phytochemical profiles found in the honey produced in this area (Patel and Verma, 2019; Sharma and Gupta, 2020). Honey is a complex amalgamation of various nutrients and components, with their concentrations varying significantly due to numerous influencing factors. Typically, most honeys share approximately 80% of their physical and chemical composition Table 3. Variations can arise from geographical and environmental conditions, the floral sources from which bees gather nectar, the specific bee species involved in honey production, and the methods used for extraction. These differences contribute to the diverse colors, viscosities, flavors, and properties of honey (Ranneh *et al*., 2021).

Primarily, honey comprises carbohydrates and water, alongside lower quantities of proteins, amino acids, enzymes, polyphenols, and minerals Table 4. Carbohydrates constitute around 80% of honey's total composition, with the majority (approximately 75%) consisting of the monosaccharides glucose and fructose. Typically, fructose is more abundant than glucose, with some exceptions found in honey derived from sources like Brassica napus and Taraxacum officinale (Miguel *et al*., 2017).

Honey can also contain trace amounts of vitamins, including riboflavin, pantothenic acid, niacin, thiamin, pyridoxine, and ascorbic acid, as well as minerals such as potassium, sulfur, chlorine, calcium, phosphorus, magnesium, sodium, iron, copper, and manganese. These components can originate from natural sources or be influenced by environmental pollutants (Ball, 2007; Bogdanov *et al*., 2007) Table 5.

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Table 1: Characteristics of honey

Characteristic	*Description*
Color	Varies from light amber to dark brown depending on floral source.
Flavor	Distinct taste influenced by nectar source.
Aroma	Unique fragrance based on botanical origin.
Crystallization	Natural process; depends on glucose-fructose ratio.
pH	3.2 - 4.5, indicating slight acidity.
Viscosity	Thick, dependent on moisture content and storage conditions.
Hygroscopicity	Ability to absorb moisture from the air.
Antimicrobial Activity	Presence of hydrogen peroxide and phenolic compounds.

The nectar collected by honeybees is the primary raw material for honey production, and the composition of this nectar significantly impacts the final honey product. Nectar's sugar content can vary widely, and bees are often attracted to nectars with higher sugar concentrations, particularly when water availability is high (Waller, 1972). In periods of nectar scarcity, bees may turn to honeydew produced by smaller insects, such as aphids, resulting in honey that contains characteristic sugars like melezitose. The greater the sugar content in the collected nectar or honeydew, the higher the carbohydrate concentration in the resulting honey (Formosa, 2017).

Amino acids are present in honey at concentrations around 0.5%, existing either as free amino acids or as constituents of proteins. Common amino acids detected in honey include proline, arginine, glutamic acid, cysteine, and aspartic acid (Miguel *et al*., 2017).

Table 2: Current honey production data in India

State	*Key honey type*
Uttar Pradesh	Largest producer, of diverse floral sources
Punjab and Haryana	Mustard and sunflower honey
Tamil Nadu	Renowned for wild forest honey
West Bengal and Bihar	Major contributors to multifocal honey

Table 3: Physicochemical characteristics of honey

Parameter	*Description*	*Standard value*
pH	Indicates acidity level and freshness	3.2–4.5
Viscosity	Thickness and flow behavior of honey	Variable depending on floral origin
Optical rotation	Measures light polarization to detect adulteration	-15°–-3°
Total solids	Dry matter content in honey	≥ 80%
Water-insoluble solids	Ensures purity and absence of foreign particles	≤ 0.1%
Electrical conductivity	Differentiates nectar and honeydew honey	≤ 0.8 mS/cm

Honey adulteration can significantly alter its overall composition, particularly affecting its sugar content and physical characteristics. Adulterated honey generally exhibits lower levels of fructose and glucose, along with a slight decrease in the glass transition temperature (Dranca *et al*., 2022).

Medicinal Importance of Honey

Honey is a complex natural product containing carbohydrates, proteins, organic acids, minerals, and various bioactive

Table 4: Main components of honey and their concentrations

Component	*Approximate concentration*	*Notes*	*References*
Carbohydrates	~80%	Predominantly monosaccharides (75%); mainly glucose and fructose, with fructose usually more abundant.	Ranneh *et al*., (2021); Miguel *et al*., (2017)
Glucose	Varies	Typically, lower than fructose, but can be higher in some honeys, such as those from Brassica napus.	Miguel *et al*., (2017)
Fructose	Varies	Generally, more abundant than glucose in most honeys.	Miguel *et al*., (2017)
Water	15–20%	Essential for honey's viscosity and stability; higher moisture content can lead to fermentation.	Ball (2007); Bogdanov *et al*., (2007)
Proteins	<0.5%	Includes enzymes and other proteins; important for the biological activity of honey.	Ranneh *et al*., (2021)
Amino Acids	~0.5%	Common amino acids include proline, arginine, glutamic acid, cysteine, and aspartic acid.	Miguel *et al*., (2017)
Minerals	Trace amounts	Includes potassium, sulfur, chlorine, calcium, phosphorus, magnesium, sodium, iron, copper, and manganese.	Ashagrie (2021); Ball (2007)
Vitamins	Trace amounts	May include riboflavin, pantothenic acid, niacin, thiamin, pyridoxine, and ascorbic acid.	Bogdanov *et al*., (2007)
Polyphenols	Varies	Contributes to the antioxidant properties of honey; concentration varies by floral source.	Ranneh *et al*., (2021)
Enzymes	Varies	Important for honey's preservation and therapeutic properties; includes diastase and invertase.	Miguel *et al*., (2017)

Table 5: Mineral composition of honey (Ashagrie Tafere, 2021)

Mineral	*Average Amount in 100 g Honey (mg)*
Calcium	4–30
Chlorine	2–20
Copper	0.01–0.1
Iron	1–3.4
Magnesium	0.7–13
Manganese	Not specified
Phosphorus	2–60
Potassium	10–470
Sodium	0.6–40
Zinc	0.2–0.5
Sulfur	Not specified

compounds, including polyphenols, flavonoids, and volatile compounds that vary based on floral sources (da Silva *et al*., 2016; Alvarez-Suarez *et al*., 2010) Table 6**.** These compounds exert multiple bioactivities, such as antioxidant, antimicrobial, anti-inflammatory, and wound-healing properties (Baltrušaitytė *et al*., 2007; Khalil *et al*., 2012). Given the rising interest in natural and alternative therapies, honey has garnered attention as a natural antioxidant and antimicrobial agent (Ahmed *et al*., 2020, 2020; Viuda-Martos *et al*., 2008).

Significance of Ecological and Floral Diversity for Honey Production

Ecological and floral diversity plays a crucial role in enhancing honey production, impacting both the quality and quantity of honey harvested. The varied plant species within a region contribute to a diverse range of nectar sources, which are essential for bees in their honey-making process. This diversity is significant for several reasons:

Nutritional Value

A wide array of flowering plants provides bees with different types of nectar, each containing unique sugars, vitamins, and minerals. This nutritional variety contributes to the overall health of bee colonies, enabling them to thrive and produce higher quantities of honey (Patel and Verma, 2019).

Flavor Profiles

The diversity of floral sources significantly affects the flavor, aroma, and color of honey. Honey derived from different plants has distinct sensory attributes that can appeal to various consumer preferences. For example, honey from eucalyptus may possess a herbal flavor, while honey from citrus blossoms can be more fruity (Singh and Sharma, 2021).

Antioxidant and Antimicrobial Properties

Different plants produce nectar rich in phytochemicals, including flavonoids and phenolic compounds, which impart antioxidant and antimicrobial properties to honey. This enhances honey's therapeutic value, making it sought after not only for its taste but also for its health benefits (Alvarez-Suarez *et al*., 2010; Bogdanov *et al*., 2008).

Table 6: Medicinal benefits of honey in modern medicine

Application	*Mechanism/Benefits*	*Citations*
Wound healing	Promotes tissue regeneration, reduces infection, and accelerates healing due to antimicrobial and anti-inflammatory properties.	Mandal and Mandal (2011); Molan (1992); Subrahmanyam (1998); Watts and Frehner (2017)
Burn treatment	Reduces inflammation, prevents scarring, and supports faster healing of burns.	Subrahmanyam (1998); Al-Waili *et al*., (2011)
Diabetic foot ulcers	Effective in treating infected wounds and improving wound closure in diabetic patients.	Mathew *et al*., (2019); Gethin and Cowman (2008)
Antimicrobial activity	Inhibits bacterial, fungal, and viral growth, targeting pathogens like *Staphylococcus aureus* and *Escherichia coli*.	Mandal and Mandal (2011); Wu and Brown (2021); Smaropoulos and Cremers (2020)
Anti-inflammatory Effects	Modulates cytokines and immune responses, reducing inflammation and pain.	Al-Waili *et al*., (2011); Silva *et al*., (2020); Tomasin and Gomes-Marcondes (2011)
Cough and Cold Relief	Soothes sore throats and reduces coughing in children and adults.	Paul *et al*., (2007); Oduwole *et al*., (2018)
Antioxidant activity	Neutralizes free radicals, protecting cells from oxidative damage and reducing oxidative stress.	Beretta *et al*., (2005); Khalil *et al*., (2010); Saxena *et al*., (2012)
Skin care	Used in creams and ointments for treating acne, eczema, and psoriasis.	Molan (1992); Abdel-Halim *et al*., (2020)
Gastrointestinal health	Provides relief in gastritis, peptic ulcers, and irritable bowel syndrome (IBS); aids in gastroprotection.	Al-Waili (2003); Samarghandian *et al*., (2017); Rocha *et al*., (2022)
Immune booster	Stimulates immune cell production, enhancing immune defense.	Mandal and Mandal (2011); Simúth *et al*., (2004); Wu *et al*., (2022)
Antimutagenic and anticancer properties	Shows the potential in suppressing mutagenic pathways and inhibiting tumor growth.	Saxena *et al*., (2012); Srinivasulu *et al*., (2018); Rocha *et al*., (2022)
Cardioprotective effects	Supports heart health by improving lipid profiles and reducing cholesterol.	Yayinie *et al*., (2022); Silva *et al*., (2021)
Dietary and nutritional benefits	Natural energy source, aids digestion as a prebiotic, supports metabolism, and enhances nutrient absorption.	Bogdanov *et al*., (2008); Samarghandian *et al*., (2017)

Biodiversity Support

The presence of diverse plant species ensures the availability of food sources for bees throughout different seasons, which is crucial for their survival and productivity. This ecological balance helps sustain bee populations, which are essential for pollination and maintaining the health of local ecosystems (Waller, 1972).

Adaptation to Environmental Changes: Regions with high floral diversity are generally more resilient to environmental changes, such as climate variability and habitat loss. This resilience supports consistent honey production even in challenging conditions, providing a stable source of income for beekeepers (Bhatt *et al*., 2015) Table 7.

Economic Importance

Diverse floral sources enhance the marketability of honey by allowing producers to offer a variety of specialty honey. This diversity can attract different consumer markets and contribute to the economic sustainability of beekeeping operations (Formosa, 2017).

Phytochemicals in Honey

Phytochemicals, secondary metabolites in plants, play crucial roles in plant defense and exhibit multiple bioactive properties in human health. In honey, the primary phytochemicals of interest include phenolic acids, flavonoids, alkaloids, and terpenoids, which contribute to its antioxidant and antimicrobial activities (Alvarez-Suarez *et al*., 2010; Bertoncini *et al*., 2007). These compounds vary significantly with floral sources and environmental conditions, impacting honey's therapeutic potential (Baltrušaitytė *et al*., 2007; Machado De-Melo *et al*., 2018). The high phenolic content in Terai honey, especially from plants like neem and mustard is associated with enhanced antioxidant and antimicrobial properties, supporting its medicinal uses (Rao *et al*., 2016; Patel and Sharma, 2019) Table 8.

Antioxidant Potential of Honey

Antioxidants combat oxidative stress, implicated in aging and chronic diseases, including cardiovascular disease and cancer (Frei *et al*., 2012; Lobo *et al*., 2010). Honey's antioxidant activity is primarily attributed to its phenolic compounds, which act as free radical scavengers, reducing oxidative damage (Khalil *et al*., 2012; Alvarez-Suarez *et al*., 2010). The Terai region's honey is particularly rich in flavonoids like quercetin, pinocembrin, and galangin, which have shown significant antioxidant activity (Kumari *et al*., 2021; Viuda-Martos *et al*., 2008). Recent studies indicate that Terai honey exhibits higher antioxidant activity than honey from other regions, possibly due to its diverse floral composition (Ahmed *et al*., 2020; Kumar *et al*., 2018).

Traditional and Contemporary Uses of Honey in Medicine

Honey has a longstanding history as a remedy in traditional medical systems, including Ayurveda and Unani, for its effects on wound healing, immunity enhancement, and digestive health (Mandal and Mandal, 2011; Eteraf-Oskouei and Najafi, 2013). These uses are supported by modern pharmacological studies, revealing honey's broad-spectrum efficacy against microbial pathogens and its antioxidant activity, beneficial in treating oxidative stress-related conditions (Kwakman and Zaat, 2012). Specific types of honey, such as Manuka honey from New Zealand, have gained worldwide attention for their standardized bioactivity profiles; however, regional varieties like those from the Terai remain underexplored (Cooper *et al*., 2010; Patel and Verma, 2019).

Table 7: Comparison of honey characteristics by floral source

Characteristic	*Description*	*References*
Floral source	Honey is derived from diverse floral sources, including wildflowers, fruit blossoms, and forest plants, contributing to its unique flavor and aroma.	Thakur *et al*., (2019)
Flavor profile	The honey has a distinct taste that can range from mildly sweet to rich and complex, often with fruity or floral notes due to varied nectar sources.	Kumar *et al*., (2020)
Color	Honey can vary in color from light amber to dark brown, influenced by the predominant floral sources and environmental factors.	Soni *et al*., (2021)
Antioxidant content	It is known for its high levels of antioxidants, contributing to its health benefits and preservation of flavor.	Bhandari *et al*., (2021)
Nutritional value	Honey contains essential vitamins, minerals, and enzymes, making it a nutritious option for consumers.	Mahato *et al*., (2022)
Therapeutic properties	This honey is recognized for its antimicrobial and anti-inflammatory properties, aiding in wound healing and overall health.	Kaur *et al*., (2018); Gupta *et al*., (2020)
Unique crystallization	Honey may exhibit a slower crystallization process due to its specific sugar composition and moisture content.	Verma *et al*., (2021)
Geographical indication	Honey may possess distinct quality recognized as a geographical indication, adding to its market value.	Tripathi *et al*., (2019)
Cultural significance	Honey holds cultural importance in local communities, often used in traditional medicine and rituals.	Awasthi *et al*., (2020)
Sustainability practices	Beekeeping practices often emphasize sustainable methods, promoting biodiversity and environmental health.	Sharma *et al*., (2022)

Table 8: Phenolic and flavonoid compounds in honey: antioxidant and antimicrobial mechanisms

Compound	*Molecular formula*	*Antioxidant property*	*Antimicrobial mechanism*	*References*
Gallic acid	$C_7H_6O_5$	Scavenges free radicals prevents lipid peroxidation	Disrupts cell membrane increases pore formation	(Borges *et al*., 2013; Ranneh *et al*., 2018)
Ferulic acid	$C_{10}H_{10}O_4$	Inhibits oxidative stress, stabilizes cell structures	Membrane disruption increases cytoplasmic leakage	(Borges *et al*., 2013; Lima *et al*., 2022)
Caffeic acid	$C_9H_8O_4$	Reduces oxidative DNA damage	Damages cell membrane integrity, induces oxidative stress	(Khan *et al*., 2021; Ouyang *et al*., 2018)
Chlorogenic acid	$C_{16}H_{18}O_9$	Neutralizes free radicals, reduces inflammation	Increases cell membrane permeability, induces nucleotide leakage	(Cheung *et al*., 2019; Górniak *et al*., 2018)
P-Coumaric acid	$C_9H_8O_3$	Inhibits lipid peroxidation, protects against DNA damage	Disrupts cell membrane binds bacterial DNA	(Borges *et al*., 2013; Ranneh *et al*., 2018)
Syringic acid	$C_9H_{10}O_5$	Antioxidant action in cellular structures	Disrupts membrane function inhibits cellular enzymes	(Ranneh *et al*., 2018; Srinivasulu *et al*., 2018)
Vanillic acid	$C_8H_8O_4$	Prevents oxidative damage to proteins and lipids	Disrupts cell membrane prevents biofilm formation	(Cheung *et al*., 2019; Qian *et al*., 2020)
Apigenin	$C_{15}H_{10}O_5$	Reduces oxidative stress markers, scavenges free radicals	Increases superoxide production, causes DNA fragmentation	(Kim *et al*., 2020; Ranneh *et al*., 2018)
Catechin	$C_{15}H_{14}O_6$	Potent free radical scavenger	Produces hydrogen peroxide, disrupting microbial cells	(Wu and Brown, 2021; Yayinie *et al*., 2022)
Luteolin	$C_{15}H_{10}O_6$	Reduces inflammation, neutralizes reactive oxygen species	Disrupts cell wall and membrane inhibits protein synthesis	(Guo *et al*., 2020; Tanleque-Alberto *et al*., 2020)
Pinocembrin	$C_{15}H_{12}O_4$	Stabilizes cellular enzymes, reduces oxidative stress	Increases membrane permeability, disrupts protein and DNA metabolism	(Tanleque-Alberto *et al*., 2020; Wu *et al*., 2022)
Galangin	$C_{15}H_{10}O_5$	Inhibits reactive oxygen species formation	Inhibits murein hydrolase gene expression	(Nešović *et al*., 2020; Ouyang *et al*., 2018)
Myricetin	$C_{15}H_{10}O_8$	The potent antioxidant effect prevents lipid peroxidation	Inhibits DnaB helicase, disrupts DNA synthesis	(Cheung *et al*., 2019; Griep *et al*., 2007)

Honey is widely used in topical applications for wound healing due to its moisturizing and antimicrobial properties, which prevent infection while promoting tissue repair (Molan, 1992; Estevinho *et al*., 2008). This suggests that Terai honey, with its distinct phytochemical composition, may offer similar or even superior wound-healing benefits compared to other regional types. Research into Terai honey's bioactivity could unlock new uses in both traditional and modern healthcare settings.

Antioxidant Mechanisms and Their Health Implications

Oxidative stress, driven by an imbalance between reactive oxygen species (ROS) and antioxidants is a major factor in aging and chronic diseases (Lobo *et al*., 2010; Frei *et al*., 2012). Antioxidants mitigate oxidative stress by neutralizing free radicals, thus protecting cellular components. Honey's antioxidant potential is largely due to its phenolic content, which exhibits free radical-scavenging activity and enhances endogenous antioxidant defenses (Baltrušaitytė *et al*., 2007; Khalil *et al*., 2012).

Studies on antioxidant activity in honey from various regions indicate that the phenolic profile, including compounds like quercetin and caffeic acid, correlates strongly with antioxidant capacity (Machado De-Melo *et al*., 2018; Kumari *et al*., 2021). Honey from the Terai region demonstrates high levels of these compounds, suggesting its potential as a natural antioxidant source that may offer protective health benefits and functional food applications (Patel and Sharma, 2019; Ahmed *et al*., 2020).

Antimicrobial Properties and Applications in Healthcare

In addition to its antioxidant potential, honey exhibits significant antimicrobial properties, attributed to its acidic pH, high sugar content, and hydrogen peroxide production, alongside various non-peroxide bioactive compounds (Molan, 1992; Cooper *et al*., 2010). These factors create an unfavorable environment for microbial growth, effectively inhibiting bacteria, fungi, and some viruses (Estevinho *et al*., 2008; Kwakman and Zaat, 2012). With rising global antibiotic resistance, honey has emerged as a promising natural alternative or adjunct to conventional antibiotics, especially for topical applications in wound care (Ahmed and Kapoor, 2020; Gupta *et al*., 2019).

Honey's antimicrobial effects are well-documented against gram-positive and gram-negative bacteria, with high efficacy

Table 9: FSSAI 2020 and IS 4941:1994 honey quality parameters

Parameter	*Description*	*Permissive limit (FSSAI 2020)*	*Permissive limit (IS 4941:1994)*	*Significance*
Moisture content	Determines water content in honey.	≤ 20%	≤ 20%	Affects shelf life and microbial stability.
Reducing sugars	Measures natural sugar content (glucose and fructose).	≥ 60% (≥ 45% for specific types like Heather)	≥ 65%	Confirms natural sugar content and purity.
Sucrose content	Detects adulteration with cane sugar or syrups.	≤ 5% (≤ 10% for honeydew and forest honey)	≤ 5%	Identifies sugar adulteration.
Hydroxymethylfurfural (HMF)	Indicates honey freshness and heat exposure.	≤ 80 mg/kg	≤ 80 mg/kg	Reflects storage conditions and heat exposure.
Specific gravity	Verifies density and authenticity.	≥ 1.35 at 27°C	≥ 1.35 at 27°C	Ensures authenticity and purity.
Acidity	Measures free acidity to confirm freshness and quality.	≤ 50 meq/kg	≤ 40 meq/kg	Ensures honey's quality and prevents fermentation.
Pollen Count	Indicates honey's floral authenticity.	Present	Present	Confirms floral source and purity.
Ash Content	Indicates mineral content in honey.	≤ 0.5%	≤ 0.5%	Reflects purity and mineral content.
Electrical conductivity	Differentiates floral and honeydew honey based on ionic content.	≤ 0.8 mS/cm for floral, ≤ 1.0 mS/cm for multifloral	≤ 0.8 mS/cm for floral, ≤ 0.8 mS/cm for multifloral	Distinguishes nectar from honeydew honey.
Diastase activity	Reflects enzymatic activity in honey, indicating freshness.	≥ 8 DN (Diastase Number)	≥ 8 Schade units	Indicates freshness and natural origin.
Free acidity	Contributes to honey's flavor and prevents fermentation.	≤ 50 meq/kg	≤ 40 meq/kg	Prevents fermentation and ensures taste.
Water insoluble solids	Ensures honey is free from foreign matter.	≤ 0.1%	≤ 0.1%	Ensures purity and absence of debris.
Apparent reducing sugars	Ensures natural sugar content in honey.	≥ 60%	≥ 60%	Confirms natural sugar content.
Total sugars	Measures overall sugar content.	≥ 65%	≥ 65%	Confirms honey's sweetness profile.
Fructose/glucose ratio	Indicates the balance between fructose and glucose sugars.	≥ 0.95 (for floral honey)	≥ 1.0 (for floral honey)	Reflects natural sugar balance in honey.
Aroma and Flavor	Confirms honey's natural aroma and flavor.	Natural, free from fermentation odor	Natural, free from fermentation odor	Ensures consumer acceptability and authenticity.
Color	Measures consistency of honey's color.	Consistent with floral source	Consistent with floral source	Indicates authenticity based on floral origin.
Markers for Rice Syrup	Identifies adulteration with rice syrup.	No detectable markers	Not specifically mentioned	Ensures no rice syrup adulteration.
Foreign oligosaccharides	Ensures there are no added sugars like rice syrup or other sources.	Below detection limits	Not specifically mentioned	Ensures no foreign sugar addition.
Cyanogenic compounds	Measures harmful compounds such as cyanide.	Below detection limits	Not specifically mentioned	Ensures safety and absence of harmful compounds.
Proline content	Indicates the natural origin of honey.	≥ 180 mg/kg	Not specifically mentioned	Reflects natural origin and authenticity.

against strains like *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli* (Brown *et al*., 2022; Mandal and Mandal, 2011). Terai honey has shown promise in vitro studies for its potent antibacterial properties, attributed to its unique honey is known for its therapeutic properties, resulting from the enzymatic action of bees on floral nectar. Its composition is influenced by geographical factors, notably in regions like Terai, and Uttar Pradesh, which boast diverse flora (White *et*

Table 10: International Standards for Honey Quality (Young, Gerard-William Zammit, and Blundell, Renald, 2023)

Criteria	*Specification/Standard*	*Findings/Comments*
Moisture content	≤ 20% (generally ≤ 18% is preferred)	High moisture can lead to fermentation.
Phenolic content	High in phenolic acids	Contributes to antioxidant properties.
Flavonoid content	Varies by floral source	Flavonoids such as quercetin and kaempferol are common.
Antioxidant activity	High antioxidant capacity	Measured through various assays (e.g., DPPH, ABTS).
Hydroxymethylfurfural (HMF) content	≤ 40 mg/kg (lower is preferred)	Indicates freshness; higher levels suggest overheating.
Sucrose content	≤ 5% (depending on floral source)	High sucrose may indicate adulteration.
Fructose and Glucose Content	≥ 60 g/100 g	Typically, higher fructose content than glucose.
Water insoluble solids content	≤ 0.1 g/100 g	Indicates purity; higher levels may indicate adulteration.
Antimicrobial activity	Effective against common pathogens (e.g., E. coli, S. aureus)	Honey's acidity and hydrogen peroxide contribute.
Diastase activity (Schade Scale)	≥ 8	Indicates freshness; lower levels may suggest degradation.
Acidity	≤ 50 meq/kg	Lower acidity is preferred; higher acidity may indicate spoilage.

al., 2019; Bogdanov *et al*., 2008). This review explores Terai honey's phytochemical composition and its antioxidant and antimicrobial properties, emphasizing its potential in traditional and modern medicine (Sharma and Gupta, 2020). Rich in bioactive compounds, Terai honey shows promise against infections and oxidative stress, aligning with sustainable health practices (Ahmed *et al*., 2020; Gupta *et al*., 2019).

National Standard Requirements for quality assessment of honey. (Table 9)

The quality and authenticity of honey are crucial for consumer health and trade. In India, the Food Safety and Standards Authority of India (FSSAI) and the Bureau of Indian Standards IS 4941:1994 regulations, have established rigorous quality benchmarks to prevent adulteration and ensure compliance.

International Standards and Regulations on Honey

The classification and standards governing what constitutes "honey" are primarily defined by two major international regulatory frameworks: the Codex Alimentarius (CA) and the European Council Directive for Honey (Table 10). These legislative guidelines, established by global regulatory bodies, have become benchmarks for honey quality across many countries. The Codex Alimentarius, first adopted by the United Nations (UN) through the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) in 1981, has seen revisions in 1987 and 2001, with further amendments in 2019. In parallel, the European Honey Directive, established by the European Council in 2001, was updated in 2014 by the European Parliament and Council (Bogdanov *et al*., 1999). Although the application of the CA standards is not mandatory for UN member states, many countries adopt their honey regulations, either independently or alongside the CA framework. Similarly, some nations within the European Union (EU) have implemented country-specific standards (Thrasyvoulou *et al*., 2018).

Both CA and EU standards define honey as a sweet substance produced by the honeybee Apis mellifera. These standards emphasize the distinction between blossom or nectar honey, derived from floral nectar, and honeydew honey, which originates from secretions of plant-sucking insects on trees. The EU regulations further elaborate on production methods and classify honey based on its processing techniques, requiring honey to be labeled by its country of origin (Codex Alimentarius Standard for Honey, 2019; Council Directive 2001/110/EC Relating to Honey, 2001; Directive 2014/63/EU of the European Parliament and Council on Honey, 2014). These classifications help set clear quality parameters, ensuring consumers receive authentic honey products aligned with international standards.

Conclusion

The unique phytochemical composition of honey, influenced by the diverse flora from which it is derived, significantly enhances its antioxidant and antimicrobial properties. These beneficial characteristics not only bolster traditional medicinal practices but also open promising avenues for modern applications in healthcare and the development of functional foods. As concerns over antibiotic resistance and conditions related to oxidative stress become increasingly prevalent, honey's potential as a natural remedy is gaining recognition.

Future research should prioritize rigorous biochemical analyses to establish standardized therapeutic properties of honey, ensuring its promotion and utilization in both local and global markets. Integrating scientific validation with traditional knowledge, honey can serve as a model for harnessing the health benefits of natural products. Such efforts will not only highlight the importance of honey in nutritional and therapeutic contexts but also support sustainable livelihoods for beekeepers, fostering a more resilient and health-conscious community. Emphasizing the need for sustainable practices in honey production is vital, as it can contribute to the conservation of biodiversity.

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