Honey Adulteration and Contamination: Impacts on Nutritional and Medicinal Value

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ABSTRACT

Honey has long been recognized for its complex nutritional composition and therapeutic potential, attributable to its naturally occurring vitamins, antioxidants, and other bioactive constituents. In recent years, however, concerns about adulteration and contamination have intensified, raising serious questions about the quality and authenticity of honey available on the market. This systematic review synthesizes global evidence on honey adulteration and contamination, evaluates how these practices affect the nutritional profile and pharmacological properties of honey, and discusses their implications for the honey-producing sectors, particularly in low- and middle-income countries and conflict-affected areas. Many such countries face constraints, including weak regulatory enforcement, limited quality-control systems, and inadequate analytical laboratory capacity, which collectively impede sectoral growth and competitiveness. Drawing on a broad range of peer-reviewed publications and technical reports, the review discusses common adulterants (including sugar syrups and artificial sweeteners) and contaminants (such as pesticides, heavy metals, and antibiotic residues). It also assesses the applicability and performance of analytical methods, including chromatographic, spectroscopic, and molecular-based techniques, for detecting these quality defects. Importantly, no primary laboratory studies quantifying adulteration and contamination in Afghan honey were identified; therefore, information on Afghanistan is used only as a qualitative, contextual example rather than as a source of analytical data. The evidence indicates that uncontrolled adulteration and contamination not only compromise honey's therapeutic efficacy but also erode consumer confidence and undermine market sustainability. To support long-term sectoral development, the review highlights the need for more robust regulatory frameworks, targeted investment in quality-assurance and testing infrastructure, and structured technical training for beekeepers and honey processors in low- and middle-income settings.

INTRODUCTION

Honey has long been cherished not only for its sweetness but also for its nutritional and medicinal properties. Across diverse civilizations, it has been used as food, medicine, and even as a sacred substance in cultural and religious practices. From an analytical perspective, honey is composed predominantly of carbohydrates (mainly fructose and glucose),

alongside smaller amounts of proteins, amino acids, enzymes, organic acids, vitamins, minerals, and a wide range of phenolic compounds and flavonoids (Samarghandian et al., 2017; Bogdanov et al., 2008; Cianciosi et al., 2018). These constituents are largely responsible for its energy-providing qualities and its reported bioactive effects, including antioxidant, antimicrobial, and anti-inflammatory activities (Samarghandian et al., 2017; Bogdanov et al., 2008). Historically, honey has been used in wound care, gastrointestinal complaints, and as a general health tonic in medical traditions such as those of ancient Egypt, Greece, China, and the Islamic world. Contemporary experimental research, including in vitro and in vivo studies, supports many of these traditional uses by demonstrating that honey can modulate oxidative stress, inflammation, and microbial growth, and may promote tissue repair and immune function (Tashkandi, 2021; Samarghandian et al., 2017; Cianciosi et al., 2018). At the same time, critical reviews of clinical evidence indicate that, although promising, high-quality human trials remain limited, and claims regarding disease prevention or treatment must therefore be interpreted cautiously (Samarghandian et al., 2017; Cianciosi et al., 2020).

Because of its complex composition and potential health effects, honey is often described in the scientific literature as a "functional food," in the sense that it may confer benefits beyond basic caloric contribution (Bogdanov et al., 2008; Cianciosi et al., 2020). This perception aligns with a broader shift in consumer preferences toward natural, minimally processed, and "chemical-free" products, encouraging many people to adopt honey as an alternative to refined sugar and artificial sweeteners. Market analyses and industry reports suggest that global honey consumption has generally increased over recent decades, partly driven by these health-oriented and "back-to-nature" trends (Fakhlaei et al., 2020). However, this growing demand has also intensified economic incentives for fraudulent practices and has exposed vulnerabilities in international honey supply chains (Fakhlaei et al., 2020). The integrity of honey, a pure and natural product, is now under threat due to widespread concerns about adulteration and contamination. Adulteration is typically defined as the deliberate addition of cheaper sweeteners—such as cane sugar, high-fructose corn syrup, rice syrup, or other sugar syrups—to increase volume and profit while lowering production costs (Fakhlaei et al., 2020; de Souza et al., 2021; Zábrodská & Vorlová, 2014). These practices alter the natural sugar profile and dilute the concentration of bioactive components, thereby compromising the nutritional and medicinal qualities that distinguish genuine honey (Fakhlaei et al., 2020; de Souza et al., 2021; Zábrodská & Vorlová, 2014; A. Review on Effect of Adulteration on Honey Properties, 2018).

Furthermore, adulterated products mislead consumers, erode trust, and create unfair competition for honest beekeepers and producers. Large-scale surveys and authenticity testing campaigns in recent years have reported alarmingly high rates of suspect or non-compliant honey samples in international trade, underscoring the scale of this problem (European Commission, 2024; Apimondia, 2024). As noted by Momtaz et al. (2023), such

fraudulent practices compromise the authenticity of honey and pose a significant obstacle for both producers and consumers who rely on its quality attributes.

Contamination represents a parallel and equally important concern. Honey can become contaminated at multiple stages—during nectar collection, hive management, harvesting, processing, and storage—through exposure to pesticides, veterinary drugs (especially antibiotics used in apiculture), heavy metals, environmental pollutants, microbes, and, in some settings, even radioactive materials (Al-Waili et al., 2012; Saad et al., 2024; Esfandiarpour et al., 2024). At sufficiently high levels or with chronic exposure, pesticide and antibiotic residues and heavy metals may pose health risks, contributing to genotoxic, carcinogenic, allergenic, or microbiome-perturbing effects (Al-Waili et al., 2012; López et al., 2014; Saad et al., 2024; Morariu et al., 2024; Trifković et al., 2017; Seraglio et al., 2021). Beyond direct health risks, contamination issues can severely damage the reputation of honey-producing regions, lead to rejections in export markets, and trigger stricter regulatory scrutiny (Al-Waili et al., 2012; Saad et al., 2024).

In many low- and middle-income and conflict-affected countries, the honey sector reflects global challenges while also facing context-specific constraints. Afghanistan is one such example: the country possesses considerable potential for honey production due to its diverse flora, favorable climatic zones, and long-standing beekeeping traditions (Hasam et al., 2020). Yet the formal industry remains underdeveloped, with limited standardization, fragmented value chains, and weak branding, which restrict both domestic value addition and access to premium export markets (Gul, 2023; Ministry of Industry and Commerce, 2023; Xinhua, 2024). Reports from national stakeholders suggest that adulteration with sugar syrups and mislabelling of botanical or geographical origin are common concerns that have damaged consumer confidence (Hasam et al., 2020; Sarwary, 2025). In some provinces, beekeepers also struggle with market access, price competition from cheaper imported honey, and inadequate technical support for quality assurance, all of which threaten the economic sustainability of local production (Gul, 2023; Amu TV, 2024; FAO, 2024).

At the same time, many of these countries, including Afghanistan, face structural limitations in regulatory enforcement and laboratory infrastructure. While numerous international studies have evaluated honey's chemical composition, antioxidant capacity, and bioactivity (Cianciosi et al., 2020; Silva et al., 2016), far fewer have focused on the specific realities of honey production in settings where food control systems are still evolving. In the present review, no peer-reviewed laboratory studies were found that directly quantify adulteration or contamination in honey produced in Afghanistan. Routine testing in such settings is constrained by limited access to advanced analytical instruments (such as isotope ratio mass spectrometry, chromatographic techniques, and spectroscopic platforms) and by inconsistent implementation of standards (Fakhlaei et al., 2020; de Souza et al., 2021; Sarwary, 2025). The few available Afghan case reports primarily describe compositional and quality attributes rather than systematic surveys of adulteration or contamination (Hasam et al., 2020; Sarwary, 2025). Therefore, this review draws primarily

on international evidence and uses Afghanistan and similar countries only as contextual examples to discuss policy and quality-control implications. These structural and analytical gaps complicate efforts to detect fraud, enforce regulations, and guarantee the authenticity and safety of honey available to consumers. These structural and analytical gaps complicate efforts to detect fraud, enforce regulations, and guarantee the authenticity and safety of honey available to consumers.

Given this context, there is a clear need for integrated analyses that link the biochemical and health-related attributes of honey with the realities of adulteration, contamination, and market structure in Afghanistan. This systematic review therefore seeks to explore how contamination and adulteration affect honey's nutritional and medicinal value, with particular emphasis on honey produced and marketed in Afghanistan; to critically evaluate the analytical methods currently used for honey quality assessment and their applicability to detecting adulteration and contamination in resource-limited settings; and to examine the specific challenges faced by Afghan honey producers—including regulatory weaknesses, limited laboratory capacity, market access constraints, and eroding consumer trust—to propose evidence-informed strategies that could support the sustainability, credibility, and growth of Afghanistan's honey industry. By addressing these interconnected aims, the review aims to contribute to both the broader scientific understanding of honey adulteration and contamination and to the development of practical policy and quality-control interventions tailored to the Afghan context.

The study aims to achieve the following objective:

- To synthesize global evidence on how honey adulteration and contamination affect its nutritional and medicinal value, with emphasis on low- and middle-income and conflict-affected countries.
- To critically review analytical methods used to assess honey quality and detect adulteration/contamination, focusing on suitability for resource-limited settings.
- To analyse challenges faced by honey producers in low- and middle-income and conflict-affected contexts and propose practical recommendations to strengthen quality control, trust, and sector resilience.

METHODS AND MATERIALS

This study was conducted as a systematic review of the literature on honey adulteration, contamination, authentication/detection methods, and the impacts of these quality defects on honey's nutritional composition and medicinal properties. The review was performed and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines.

Eligibility Criteria

Studies and reports were eligible for inclusion if they met all of the following criteria:

- Population/material: honey intended for human consumption (raw or processed).

- Topic: addressed at least one of the following:

    - Honey adulteration, fraud, authenticity, or mislabeling
    - Chemical contamination (pesticides, antibiotics/veterinary drug residues, heavy metals, environmental pollutants)
    - Microbiological contamination (bacteria, yeasts, molds, spores)
    - Analytical methods for authentication and contamination detection
    - Nutritional composition and/or health-related properties (antioxidant, antimicrobial, anti-inflammatory, wound healing, etc.) Relevant to honey quality

- Study type: original research articles (laboratory/analytical studies, monitoring studies, experimental studies), systematic reviews, major narrative reviews, and institutional/governmental technical reports.

- Language and time: English-language publications up to 31 December 2025.

Exclusion criteria

- studies focusing exclusively on non-honey bee products (e.g., propolis, royal jelly, bee pollen)
- conference abstracts without sufficient methodological detail
- editorials, commentaries, and opinion papers without primary data
- Studies not available in English

Information Sources

A comprehensive search was performed in the following databases:

- PubMed
- Scopus
- Embase
- ScienceDirect
- Google Scholar

To capture relevant grey literature, the review also included screening of documents from international organizations and authorities, including FAO, WHO, national ministries, food safety authorities, and regulatory agencies. In addition, reference lists of included studies and major reviews were manually screened to identify further eligible records.

Search Strategy

Search strings were developed using a combination of controlled vocabulary (where applicable) and free-text terms. The strategy included keywords related to honey, authenticity, contamination, and analytical detection. Core terms included combinations of:

- "honey"
- "adulteration" OR "fraud" OR "authenticity" OR "mislabeling" OR "sugar syrup"
- "contamination" OR "residues" OR "pesticides" OR "antibiotics" OR "heavy metals" OR "microbial"
- "detection methods" OR "authentication" OR "NMR" OR "IRMS" OR "HPLC" OR "GC–MS" OR "UHPLC–MS/MS" OR "spectroscopy"
- context-related terms including "low- and middle-income countries," "developing countries," "conflict-affected," and country names including "Afghanistan."

Searches were performed from database inception to 2025. No lower year limit was applied, although most included studies were published after 2000.

Study Selection

All retrieved references were exported into a reference manager, and duplicates were removed. Study selection was performed in two stages:

1. Title and abstract screening to remove clearly irrelevant records.
2. Full-text assessment of all potentially eligible studies.

Both authors independently screened titles/abstracts and assessed full texts. Any disagreements were resolved through discussion and consensus. Reasons for exclusion at the full-text stage were recorded.

Data Extraction

Data were extracted into a standardized table designed before extraction. The extracted variables included:

- author and year
- country/region and study setting
- study type and design
- sample size and honey characteristics (botanical/geographical origin where reported)
- adulterants or contaminants assessed
- analytical methods and instrumentation
- main outcomes (adulteration/contamination findings; composition; bioactivity; method performance)
- Key limitations and relevance to LMIC and conflict-affected contexts

Quality appraisal (methodological assessment)

Given the wide heterogeneity of study designs (analytical chemistry studies, monitoring surveys, experimental bioactivity studies, and reports), methodological quality was appraised descriptively using criteria appropriate to each design. The appraisal focused on:

- clarity of objectives and outcomes
- sampling method and representativeness

- analytical validation and reporting (calibration, reference standards, LOD/LOQ, repeatability)
- transparency and completeness of reporting
- consistency between conclusions and results

This appraisal was used to interpret the strength of evidence rather than to exclude studies solely on quality grounds.

Data Synthesis

Due to substantial heterogeneity across included studies in terms of design, analytical methods, and outcome reporting, statistical pooling and meta-analysis were not appropriate. Therefore, results were synthesized using a narrative thematic synthesis, structured around four evidence domains:

1. Honey composition and nutritional/medicinal properties
2. Honey adulteration and its impacts on composition and bioactivity
3. Contamination types, sources, and associated risks
4. analytical methods for honey authentication and contamination detection, with emphasis on feasibility in resource-limited settings

Afghanistan-Specific Evidence and Evidence Gap

Afghanistan was included explicitly in the search strategy. However, no eligible primary analytical studies were identified that directly quantified adulteration or contamination in Afghan honey. Therefore, Afghanistan is discussed only as a qualitative contextual case, using available descriptive reports and sector information to highlight market, regulatory, and laboratory capacity challenges and to identify priority research gaps.

FINDINGS

The systematic search across PubMed, Scopus, Embase, ScienceDirect, and Google Scholar identified a substantial body of literature addressing honey composition, adulteration, contamination, and analytical authentication. After duplicate removal and eligibility screening, studies were included if they provided evidence on at least one of the predefined domains: (i) nutritional and medicinal properties of honey, (ii) adulteration and authenticity, (iii) chemical or microbiological contamination, or (iv) analytical detection methods. Most included studies were published after 2000 and consisted of analytical laboratory investigations, contamination monitoring studies, and major evidence syntheses. Although Afghanistan was explicitly included in the search strategy, no peer-reviewed primary analytical studies were identified that directly quantified the prevalence of adulteration or contaminant levels in Afghan honey. Therefore, Afghanistan is discussed as a contextual case based on sectoral and policy evidence rather than laboratory data. Due to heterogeneity in study designs, analytical platforms, and reported outcomes, findings were synthesized narratively across thematic domains.

Nutritional Composition and Bioactive Properties of Honey

Across included studies, honey was consistently described as a carbohydrate-rich natural product. Its carbohydrate profile is dominated by fructose (approximately 38%) and glucose (approximately 31%), providing a rapid energy source (Cianciosi et al., 2020; Miguel et al., 2017). Oligosaccharides, which represent approximately 5–10% of the carbohydrate content, have been reported to potentially contribute to prebiotic effects by promoting beneficial gut microbiota (Silva et al., 2016; Afrin et al., 2020). Honey also contains trace amounts of proteins, including amino acids and enzymes such as glucose oxidase, diastase, and invertase, which are important for physicochemical stability and antimicrobial properties (Ranneh et al., 2021; Fakhlaei et al., 2020). Vitamins (e.g., vitamin C and B-group vitamins) and minerals (e.g., potassium, calcium, magnesium, phosphorus, and iron) were detected at low concentrations and are generally insufficient to meet daily nutritional requirements (Hasam et al., 2020; Fakhlaei et al., 2020). Organic acids such as gluconic acid contribute to honey's acidity and sensory profile (Kanbur et al., 2021).

Physicochemical characteristics—including low water activity and acidic pH (commonly 3.4–6.1)—create conditions unfavorable to microbial growth (Silva et al., 2016; Ranneh et al., 2021). The enzyme glucose oxidase, which produces hydrogen peroxide, has repeatedly been identified as a key contributor to antimicrobial activity (Fakhlaei et al., 2020). Experimental evidence (primarily in vitro and animal studies) supports antioxidant, antimicrobial, and anti-inflammatory effects largely attributed to polyphenolic compounds (Cianciosi et al., 2020; Miguel et al., 2017). However, high-quality clinical trials remain limited, and therapeutic dosing is not standardized. Processing methods were consistently identified as influencing quality: raw or minimally processed honey retains higher levels of bioactive compounds, while excessive heating and filtration may reduce enzyme activity and antioxidant capacity (Hasam et al., 2020; Fakhlaei et al., 2020).

Honey Adulteration: Practices, Impacts, and Detection

The included evidence consistently identifies honey as one of the most frequently adulterated food commodities globally (Biswas et al., 2023; Soares et al., 2017). Adulteration practices are economically motivated and take multiple forms.

Types of Adulteration

Commonly reported adulterants include cane and beet sugar, glucose syrup, fructose syrup, corn syrup, rice and wheat syrups, inverted sugar syrups, and high-fructose inulin syrup (Ismail & Ismail, 2018; Corradini et al., 2012). Adulteration strategies were categorized into:

- Direct adulteration (post-harvest addition of sweeteners)
- Indirect adulteration (feeding bees artificial syrups)
- Blending (mixing high-quality honey with lower-quality honey)
- Mislabeling of botanical or geographic origin

Across studies, adulteration was associated with dilution of enzymes and polyphenols, reduced antimicrobial activity, and alterations in natural sugar ratios. Although excessive free-sugar intake is linked to metabolic risk, direct causal associations between consumption of adulterated honey and chronic disease outcomes have not been firmly established (Wang et al., 2015). Because the mechanisms and detection methods for adulteration were highly heterogeneous across studies, the main adulteration strategies and analytical approaches were synthesized and mapped (Table 1).

Table 1. *Common honey adulteration practices and analytical approaches used for detection*

Adulteration type	Examples reported	Purpose	Key analytical methods	Strengths	Limitations (LMIC context)
Direct adulteration	Cane sugar, corn syrup, rice syrup, glucose/fructose syrup	Increase volume/profit	HPLC; GC–MS; MIR/NIR + chemometrics; ¹H NMR	Strong detection capability	Requires reference databases and equipment
Indirect adulteration	Feeding bees C_3/C_4 syrups	Produce low-cost honey	IRMS; LC–IRMS; NMR fingerprinting	Reliable isotope discrimination	High cost; limited isotope labs
Blending	Mixing premium & inferior honey	Maintain label while increasing volume	NMR; PCA/LDA; melissopalynology	Useful for classification	Natural variability complicates interpretation
Botanical mislabelling	False floral claims	Price inflation	Melissopalynology; DNA profiling; LC markers	Floral origin verification	Requires trained analysts
Geographic mislabelling	False country/province origin	Premium branding	IRMS + elemental profiling; chemometrics	Strong when combined	Needs regional reference libraries

Advanced spectroscopic approaches, such as UV–Vis, MIR, and NIR, combined with chemometrics, have demonstrated promising sensitivity for detecting added sugars, in some cases at levels near 10% (De Souza et al., 2021; Skaff et al., 2022). Emerging tools, including biosensors and Raman spectroscopy, may improve rapid screening but remain limited for routine application in low-resource settings (Se Kuan Wei et al., 2019). Natural compositional variability and evolving fraud strategies remain major authentication challenges (Walker et al., 2022).

Honey Contamination: Categories, Sources, and Detection

Contamination may occur during nectar collection, hive management, processing, storage, or through environmental exposure. The included studies consistently categorized contaminants into four major groups: pesticide residues, antibiotic residues, microbiological hazards, and heavy metals (Bogdanov, 2006; Seraglio et al., 2021).

To provide a structured overview of contamination evidence, the main contaminant categories, representative examples, and typical sources were synthesized across the

included literature (Table 2). The authors developed this table and do not represent data from a single study.

Table 2. *Major contaminant groups identified in honey across included studies*

Contaminant category	Representative examples reported	Typical source of entry into honey
Pesticides	Acaricides (e.g., amitraz, coumaphos), insecticides, fungicides, herbicides	Agricultural spraying; contaminated nectar/pollen; hive treatments
Antibiotics/veterinary drugs	Oxytetracycline, streptomycin, erythromycin, sulfonamides	Disease control in beekeeping: misuse of veterinary drugs
Microbiological hazards	*Bacillus* spp., yeasts, molds, *Clostridium botulinum* spores	Dust, pollen, equipment contamination, improper storage
Heavy metals	Pb, Cd, Hg, As (sometimes Ni and Cr species)	Environmental pollution; soil/water contamination; industrial emissions
Other environmental contaminants (less frequent)	PAHs, dioxins (rare), radioactive residues (rare)	Industrial emissions; environmental incidents

To synthesize contamination evidence across heterogeneous studies, contaminant categories, sources, and analytical approaches were mapped (Table 3).

Table 3. *Major contamination categories in honey, typical sources, and analytical detection methods*

Contaminant category	Examples	Main sources	Analytical methods reported	Reported implications
Pesticides	Acaricides, insecticides, fungicides	Agricultural spraying; hive treatments	GC–MS; LC–MS/MS; UHPLC–MS/MS	Regulatory non-compliance; export rejection
Antibiotics	Oxytetracycline, streptomycin, erythromycin	Veterinary misuse in apiculture	LC–MS/MS; immunoassays	Antimicrobial resistance; allergic reactions
Microorganisms	*Bacillus* spp.; yeasts; *Clostridium botulinum*	Dust; pollen; equipment; storage	Culture; PCR; 16S sequencing	Infant botulism risk; spoilage
Heavy metals	Pb, Cd, Hg, As	Environmental pollution; soil; water	ICP-MS; AAS; ICP-OES	Chronic exposure risk; environmental indicator

Pesticide Residues

Pesticide residues were frequently detected in regions with intensive agricultural activity. Regulatory Maximum Residue Limits (MRLs) vary internationally, and detection commonly relies on chromatographic techniques following extraction procedures such as SPE and LLE (Al-Waili et al., 2012; Souza Tette et al., 2016).

Antibiotic Residues

Antibiotic residues were linked to disease control practices in apiculture. Advanced mass-spectrometric techniques were widely reported for monitoring compliance, particularly in export-oriented markets (Bonerba et al., 2021).

Microbiological Hazards

Although honey inhibits most microbial growth, spores of *Clostridium botulinum* have been reported in multiple countries and pose a risk to infants. Detection methods ranged from culture-based assays to PCR and molecular techniques (Gacić et al., 2015).

Heavy Metals

Heavy metal contamination was associated with environmental pollution and industrial activities. Risk assessment approaches frequently use the Target Hazard Quotient (THQ), with risk levels strongly dependent on regional exposure and consumption patterns (Brifa et al., 2020).

Afghanistan: Context and Evidence Gap

Evidence concerning Afghanistan was primarily descriptive. Reports indicate approximately 3,397 bee farms and an annual production of nearly 2,200 tons (Ministry of Industry and Commerce, 2023; Xinhua, 2024). Development programs have supported rural livelihoods, including women's participation (World Bank, 2015; FAO, 2024). However, challenges include competition from imported honey, limited laboratory capacity, weak regulatory enforcement, and climate-related production impacts (Gul, 2023; Weqar et al., 2024). Importantly, this systematic review identified no peer-reviewed analytical surveillance studies quantifying adulteration or contamination in Afghan honey, representing a significant research and policy gap.

DISCUSSION

This review synthesized evidence on honey's nutritional and medicinal properties, the global burden of honey adulteration and contamination, and the analytical approaches used for authentication and safety assessment, with particular attention to low- and middle-income and conflict-affected settings. The review also examined Afghanistan as a contextual case, recognizing that no peer-reviewed analytical surveillance studies were identified that directly quantify adulteration prevalence or contaminant levels in Afghan honey. Overall, the findings demonstrate that honey's perceived nutritional and therapeutic value is closely linked to its biochemical integrity, and that adulteration and contamination represent major threats to consumer trust, public health protection, and sector sustainability.

The included literature consistently describes honey as a carbohydrate-rich food dominated by fructose and glucose, with smaller contributions from oligosaccharides, enzymes, organic acids, minerals, vitamins, and polyphenolic compounds (Cianciosi et al., 2020; Miguel et al., 2017; Silva et al., 2016). Across compositional and experimental studies, polyphenols and enzymatic activity were repeatedly associated with antioxidant and antimicrobial effects, supporting honey's long-standing use in wound care and gastrointestinal conditions (Ranneh et al., 2021; Fakhlaei et al., 2020). However, this systematic review confirms that much of the evidence supporting medicinal effects derives from in vitro experiments, animal studies, and small heterogeneous clinical investigations. As

such, while the biological plausibility of honey's health effects is strong, the clinical evidence base remains insufficient to support broad therapeutic claims or standardized dosing recommendations (Afrin et al., 2020; Khan et al., 2007; Gündoğdu et al., 2019).

An important cross-cutting finding was that processing and handling influence bioactive retention. Multiple studies reported that excessive heating and filtration reduce enzyme activity and antioxidant capacity, suggesting that quality standards should not only address adulteration and contamination but also define acceptable processing conditions (Hasam et al., 2020; Fakhlaei et al., 2020). Similar challenges have been documented in other LMIC contexts, such as Ethiopia, where honey quality loss during processing is a barrier to market differentiation and export competitiveness (Lomiso et al., 2021). Evidence from such settings suggests that certification, consumer education, and value-chain improvements may help producers capture higher market value for raw or minimally processed honey.

The review findings confirm that honey adulteration is a widespread global problem, consistent with international evidence identifying honey as one of the most frequently adulterated foods (Soares et al., 2017; Biswas et al., 2023). The most commonly reported adulterants across studies included sugar syrups and industrial sweeteners (e.g., corn, rice, wheat, inverted sugar syrups), which are added directly after harvest or indirectly through feeding practices (Ismail & Ismail, 2018; Corradini et al., 2012; Fakhlaei et al., 2020). Adulteration not only misleads consumers and undermines fair trade but also reduces honey's nutritional and medicinal value by diluting enzymes, polyphenols, and other bioactive constituents.

The review also indicates that linking honey adulteration directly to chronic disease outcomes remains challenging. While adulterated honey increases the proportion of rapidly absorbable sugars and contributes to overall free sugar intake—an established risk factor for metabolic disorders—few studies directly measure health outcomes specifically attributable to adulterated honey consumption (Wang et al., 2015). Therefore, the public health argument is currently strongest when framed as a quality, consumer protection, and dietary sugar issue rather than as a proven cause of specific chronic disease outcomes.

A key contribution of this systematic review is the synthesis of evidence on analytical methods for honey authentication and their feasibility in low-resource contexts. High-specificity approaches such as IRMS, LC–IRMS, ¹H NMR, and chromatographic methods (HPLC, GC–MS, UHPLC–MS/MS) were consistently reported as reliable for detecting syrup adulteration and for supporting geographic or botanical origin claims (Guler et al., 2014; Biswas et al., 2023; Tsagkaris et al., 2021). However, these methods require expensive equipment, trained personnel, and reference databases, limiting routine application in LMIC and conflict-affected countries.

Studies also highlight growing interest in lower-cost screening tools, including MIR/NIR spectroscopy and UV–Vis spectroscopy combined with chemometrics, which demonstrated promising detection capability in controlled datasets (De Souza et al., 2021; Skaff et al.,

2022). These approaches may offer a realistic pathway for tiered quality-control systems, where rapid screening is followed by confirmatory testing in specialized laboratories. Nevertheless, the review confirms that authentication remains technically challenging because natural honey composition varies substantially by floral source, geography, and season, and fraud strategies continue to evolve (Walker et al., 2022; Danieli & Lazzari, 2022). Therefore, effective authentication requires not only laboratory tools but also strong standards, reference libraries, and traceability systems.

Emerging digital and technological solutions, including blockchain-based traceability and biosensor platforms, have been proposed as future strategies to improve transparency and detection (Se Kuan Wei et al., 2019). However, evidence supporting their cost-effectiveness and scalability in LMIC and conflict-affected settings remains limited, and implementation barriers (infrastructure, governance, and institutional capacity) are likely substantial (Hossain et al., 2020).

This review identified pesticide residues, antibiotic residues, microbiological hazards, and heavy metals as the dominant contamination categories across the literature (Bogdanov, 2006; Seraglio et al., 2021). Pesticide residues were widely discussed in relation to agricultural exposure and in-hive treatments, with risk depending on local pesticide use patterns and enforcement of Maximum Residue Limits (MRLs) (Al-Waili et al., 2012). Antibiotic residues were frequently linked to apicultural disease control practices, and the review confirms that this issue has both direct consumer safety implications and broader concerns related to antimicrobial resistance (Bonerba et al., 2021). Honey's physicochemical properties generally limit microbiological contamination, but *Clostridium botulinum* spores remain a recognized hazard, particularly for infants (Gacić et al., 2015). Heavy metals, including Pb, Cd, Hg, and As, were repeatedly associated with environmental pollution, and risk assessments using THQ demonstrate that risk is context-dependent and can become significant in polluted regions or among high-frequency consumers (Brifa et al., 2020; Zergui et al., 2023).

Comparative evidence from neighboring and regional countries provides important contextual relevance for Afghanistan. For example, studies from Pakistan reported contamination patterns reflecting local industrial and environmental pollution, suggesting that Afghanistan may face similar risks, depending on local agricultural chemical use and environmental conditions (Zergui et al., 2023). However, without Afghan analytical surveillance data, these comparisons remain indirect and should be interpreted cautiously.

The review highlights that Afghanistan has substantial potential for honey production and a long history of beekeeping, with reported annual production of approximately 2,200 tons and thousands of bee farms (Ministry of Industry and Commerce, 2023; Xinhua, 2024). Development initiatives such as AREDP have supported training and equipment distribution, contributing to productivity and livelihood support, including for women and marginalized groups (World Bank, 2015; FAO, 2024). Despite this potential, Afghan producers face significant constraints, including competition from low-priced imports, weak branding, limited quality-control infrastructure, and persistent concerns about the presence of fake or

inferior honey (Gul, 2023; Amu TV, 2024). Climate-related impacts, including altered floral availability and colony productivity, represent an additional emerging threat (Weqar et al., 2024).

The most important Afghanistan-related finding of this systematic review is the absence of peer-reviewed analytical studies quantifying the prevalence of adulteration and contaminant levels in Afghan honey. This evidence gap limits risk assessment, hinders regulatory enforcement, and constrains the development of credible quality certification and export strategies. The review therefore supports the need for national surveillance studies, laboratory capacity development, and the establishment of minimum honey quality standards aligned with international frameworks.

Taken together, the findings suggest that improving honey quality in LMIC and conflict-affected settings requires an integrated approach combining: (i) regulatory standards and enforcement, (ii) feasible quality-control systems using tiered analytical testing, (iii) beekeeper and processor training, and (iv) market mechanisms that reward authenticity and safe production. For Afghanistan, priority actions include investment in basic and intermediate laboratory infrastructure, structured training programs for beekeepers and processors, improved packaging and labeling standards, and development of cooperative-based quality assurance models to strengthen bargaining power and market access.

Future research should prioritize: (1) systematic national sampling of honey for adulteration and contamination; (2) validation of cost-effective screening tools such as NIR/MIR spectroscopy under Afghan conditions; and (3) assessment of traceability systems and cooperative models for strengthening the value chain. Generating this evidence is essential to protect consumers, strengthen trust, and enable Afghanistan's honey sector to compete in domestic and export markets.

CONCLUSION

This systematic review synthesized global evidence on honey's nutritional and medicinal properties, adulteration practices, contamination risks, and analytical detection methods, with particular attention to low- and middle-income and conflict-affected settings, including Afghanistan. Honey is consistently described as a carbohydrate-rich natural product that contains bioactive compounds, such as polyphenols and enzymes, with antioxidant and antimicrobial activity. However, most therapeutic evidence comes from in vitro studies, animal models, and small heterogeneous clinical investigations. High-quality, large-scale human trials remain limited, and standardized therapeutic dosing has not been established. Therefore, health claims regarding disease prevention or treatment in humans should be interpreted cautiously. Adulteration remains a major global integrity challenge, most commonly involving the addition of sugar syrups and other sweeteners. These practices compromise compositional authenticity, dilute bioactive components, and reduce the nutritional and medicinal value of genuine honey. Adulteration also undermines consumer trust and creates unfair competition for legitimate producers. Although adulterated honey

increases overall free-sugar intake, current evidence does not clearly establish direct causal links to specific chronic diseases. Advanced analytical techniques such as IRMS, NMR, chromatographic methods, and chemometric spectroscopy provide strong detection capacity.

Nevertheless, routine implementation of these methods is constrained in many low-resource settings due to cost, technical complexity, and limited laboratory infrastructure. Contamination with pesticides, veterinary drug residues, microbiological hazards, and heavy metals represents an additional safety concern. The magnitude of contamination risk varies by region depending on environmental exposure, agricultural practices, regulatory enforcement, and consumption patterns. In Afghanistan, no peer-reviewed analytical surveillance studies were found that directly quantify the prevalence of adulteration or contaminant levels in local honey, creating a critical evidence gap. Limited laboratory monitoring restricts risk assessment, regulatory enforcement, and export competitiveness. Strengthening the honey sector in Afghanistan and similar contexts requires investment in laboratory capacity, tiered authentication systems that are feasible, improved regulation, and producer training. Future research should prioritize nationally representative sampling, validation of low-cost screening tools, and development of traceability systems suited to resource-limited environments.

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AUTHORS CONTRIBUTIONS

- Javed Rahimi conceptualized the study, developed the review framework, and wrote the first draft of the manuscript.
- Ayaz Khan Naseri contributed to the literature review, provided critical insights into the economic and extension aspects of the Afghan honey industry, and assisted with data interpretation.
- Both authors contributed to revising and refining the manuscript.
- All authors reviewed and approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

No new data were generated in this study. Data supporting the findings of this systematic review are available within the article and its reference list.

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