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Contaminants in Honey: A Comprehensive Review of Sources, Risks, and Detection Methods

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Abstract

Honey, a natural product revered for its nutritional and therapeutic properties, has traditionally been used as a food and medicine, yet it is now facing an increasing risk of contamination from multiple sources. In this review, we summarize the major contaminants of honey, such as pesticides, heavy metals, antibiotics, microbial agents, and other adulterants. Additionally, we critically assess the ways these substances contaminate the honey supply, which include environmental pollution, agricultural practices, beekeeping, and post-harvest handling. The review also elaborates on the health risks associated with the contaminants for consumers, the impacts on global trade and food safety, and the broader implications. Moreover, the review analyzes some of the most current methods of extracting contaminants, including chromatographic, spectroscopic, and molecular methods, to evaluate their effectiveness and limitations. This review intends to guide future research and policy decisions alongside regulatory provisions and best practices to ensure honey's safety and quality in the international market.

Categories: Food and Pharmaceutical Engineering, Biotechnology and Engineering, Chemical Process Optimization
Keywords: phytochemicals, nutritional, health risk, health benefits, contaminants

Introduction And Background

Honey, a natural substance produced by honeybees from the nectar of flowering plants, has long held a revered place in human culture, nutrition and medicine, dating back thousands of years to ancient civilizations that prized it not only as a food product but also for its healing and antimicrobial properties [1]. With the increasing demand for natural and functional foods, honey's popularity has grown across global markets, supported by its rich composition of sugars, enzymes, vitamins, minerals, phenolic compounds, and antioxidants. However, alongside this growing demand comes the critical challenge of ensuring its purity and safety, as honey is susceptible to a wide range of contaminants that may enter the product through various environmental, agricultural, and apicultural pathways [2]. The issue of honey contamination has gained heightened attention in recent years due to escalating concerns about food safety, the integrity of global food trade, and the long-term impacts of consuming contaminated products on human health [3]. Contaminants in honey can be broadly categorized into chemical, biological, and physical groups, with chemical contaminants being the most prevalent and extensively studied. Among these, residues of pesticides, antibiotics, heavy metals, and industrial pollutants are commonly detected and represent major concerns for consumers, producers, and regulators alike. Pesticides such as neonicotinoids, organophosphates, and pyrethroids are often used in agricultural settings to protect crops, but they can unintentionally contaminate nectar, pollen, and water sources that bees interact with, resulting in their eventual transfer into honey [4]. These compounds are known to be persistent in the environment and can accumulate within the beehive, posing toxicity risks not only to bees contributing to colony collapse disorder and declining bee populations but also to human consumers through the ingestion of tainted honey [5]. Similarly, heavy metals such as lead, cadmium, arsenic, and mercury may be introduced into honey through environmental pollution from industrial activities, vehicular emissions, contaminated water sources, or soil in which flowering plants grow [6]. These metals are non-biodegradable and can accumulate in the human body, leading to a range of health issues, including neurological damage, organ failure, and developmental disorders, especially in vulnerable populations such as children and pregnant women [7]. Another major concern is the presence of antibiotics in honey, which are commonly used in apiculture to prevent or treat bacterial infections like American foulbrood and European foulbrood in bee colonies. While these treatments are often necessary for maintaining hive health, improper or excessive use can result in antibiotic residues being present in the final honey product [8]. The consumption of such residues not only violates food safety regulations in many countries but also contributes to the broader and more alarming problem of antibiotic resistance, undermining the efficacy of critical drugs in human medicine [9]. In addition to chemical contaminants, biological contaminants such as bacteria, yeasts, and molds can also compromise honey quality, particularly when hygiene standards during harvesting, processing, or storage are inadequate. Of particular concern is the presence of *Clostridium botulinum* spores in honey, which, although harmless to adults, can lead to infant botulism a rare but potentially fatal condition affecting infants under one year of age [10]. Furthermore, physical contaminants such as wax particles, debris, or even adulterants like sugar syrups may be present in

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commercially sold honey, either unintentionally due to poor handling or intentionally through economic adulteration aimed at increasing volume and profits. Given the complexity and variety of contaminants that can affect honey, robust and sensitive analytical methods are essential for their detection, quantification, and monitoring [11]. Advanced chromatographic techniques such as gas chromatography (GC), liquid chromatography (LC), and their respective mass spectrometry couplings (GC-MS, LC-MS) have become standard tools for identifying trace levels of pesticides and antibiotic residues in honey samples [12]. Spectroscopic methods, including atomic absorption spectroscopy (AAS) and inductively coupled plasma mass spectrometry (ICP-MS), are widely used for the detection of heavy metals. Enzyme-linked immunosorbent assays (ELISAs) offer a cost-effective and rapid screening option for many contaminants, although their specificity can vary depending on the target analyte [13]. Emerging technologies such as biosensors, nanotechnology-based assays, and molecular methods are also being explored for their potential to enhance the speed, sensitivity, and accessibility of honey testing [14]. From a regulatory perspective, various national and international bodies have established maximum residue limits (MRLs) and safety thresholds for contaminants in honey to protect consumer health and facilitate fair trade [15]. For instance, the Codex Alimentarius Commission, the European Union, the United States Food and Drug Administration, and other national agencies have outlined permissible levels for a range of substances and provided guidance on sampling, testing, and enforcement protocols [16]. However, disparities in regulations and testing capacities among countries can create challenges in the global honey trade, as products deemed safe in one jurisdiction may be rejected in another due to differing standards or detection limits. Moreover, the widespread issue of honey adulteration where sugar syrups from rice, corn, or cane are added to increase volume has further complicated efforts to ensure product authenticity and transparency in the supply chain [17]. Addressing the issue of honey contamination requires a holistic and coordinated approach that spans environmental stewardship, sustainable agricultural practices, responsible beekeeping, advanced analytical testing, and stringent regulatory enforcement [18]. It also demands ongoing research to better understand the pathways and impacts of contaminants, develop improved detection technologies, and formulate practical mitigation strategies [19]. In this review, we aim to provide a comprehensive synthesis of current knowledge regarding the major types of contaminants found in honey, explore their sources and routes of entry, assess the associated health and environmental risks, and evaluate the existing and emerging methods for their detection and control. By compiling and critically analyzing findings from scientific literature, regulatory reports, and global monitoring efforts, this work seeks to inform researchers, industry stakeholders, policymakers, and consumers about the current landscape of honey contamination, and to highlight key priorities for ensuring the continued safety, quality, and sustainability of this vital natural product.

Review

Name of plant	Plant family	Name of honey	Extract	Phytochemicals present	Country
Solidago virgaurea	Asteraceae	Goldenrod honey	Aqueous	Flavonoids, tannins & organic acids	Europe
Rosmarinus officinalis	Lamiaceae	Rosemary honey	Aqueous	L-phenylalanine & raffinose	Spain
Robinia pseudoacacia	Fabaceae	Acacia honey	Aqueous	Phenolic acids & flavonoids	USA
Castanea pumila	Fagaceae	Chestnut honey	Aqueous	Phenolic acids & flavonoids	USA
Leptospermum scoparium	Myrtaceae	Manuka honey	Aqueous	Flavonoids & phenolics	Australia
Tilia cordata	Malvaceae	Basswood honey	Aqueous	Hydrocarbons, ethers & aromatic compounds	Europe
Persea americana	Lauraceae	Avocado honey	Aqueous	Phenolics, Quercetin, Apigenin, Kaempferol	USA

TABLE 1: Varieties of honey and their phytochemicals in aqueous extract

Refer to [12,14]

Sources of contamination

The primary sources of honey contamination can be categorized into environmental and beekeeping-related factors. Environmental contaminants include pesticides, heavy metals, and organic pollutants. Pesticides, such as neonicotinoids, are widely used in agriculture to protect crops from pests. These chemicals can be absorbed by plants and subsequently transferred to honey through nectar and pollen [20]. Heavy metals like lead, cadmium, and mercury can enter honey through polluted water sources or contaminated soil, accumulating in the bees' bodies and eventually in the honey they produce. Organic pollutants, including polychlorinated biphenyls, can also find their way into honey through

environmental pollution. Beekeeping practices contribute to contamination through the use of veterinary drugs and chemicals. Antibiotics, such as tetracyclines and sulfonamides, are employed to prevent or treat diseases in bee colonies [21]. While these treatments are essential for colony health, their residues can persist in honey, posing health risks to consumers. Similarly, acaricides used to control the *Varroa destructor* mite can leave residues in honey if not properly managed. Additionally, the use of certain chemicals in hive maintenance and pest control can introduce contaminants into honey [22].

Methods

A systematic search of peer-reviewed scientific literature was performed using several major academic databases, including PubMed, ScienceDirect, Web of Science, and Google Scholar. The search was limited to publications in English from 2000 to 2025 to capture contemporary issues and technological advancements in detection methods. Keywords and search terms included combinations such as “honey contamination,” “pesticide residues in honey,” “heavy metals in honey,” “antibiotics in apiculture,” “detection methods for honey contaminants,” and “honey safety regulations.” Boolean operators (AND, OR, NOT) were used to refine search results and ensure relevant coverage. From each included article, key data were extracted and organized into categories: types of contaminant (e.g., pesticide, heavy metal, antibiotic, microbial), source or pathway of contamination, geographical origin of samples, analytical detection method used, detection limits, regulatory context, and health impact assessments [23]. This structured approach enabled comparison across studies and helped identify emerging trends and gaps. Extracted data were synthesized using thematic analysis to identify recurrent patterns, technological advancements, and regional differences in contaminant prevalence and regulation. Analytical techniques were compared in terms of sensitivity, specificity, cost, and practicality in both laboratory and field settings [24]. A comparative review of global regulatory standards was also conducted to highlight inconsistencies and alignments among major honey-producing and importing countries.

Outcome of study

The review identified and synthesized findings from over 150 peer-reviewed studies and regulatory reports spanning more than 30 countries. Only 48 related studies have been included for the recent data analysis excluding the other 102 articles. The data revealed that honey contamination is a global issue, with regional differences in contaminant types, prevalence, and regulatory enforcement. The results are categorized by contaminant type and detection method.

Pesticide Residues

Pesticide residues were the most frequently reported chemical contaminants in honey. Neonicotinoids (especially imidacloprid and thiamethoxam), organophosphates, and pyrethroids were the most commonly detected compounds [25]. Studies across Europe, Asia, and Latin America reported neonicotinoids in up to 80% of honey samples, often in concentrations exceeding EU MRLs. Longitudinal studies suggested a correlation between pesticide use intensity in agriculture and residue levels in honey, particularly in crops such as sunflower, canola, and citrus. Detection was primarily achieved using LC-MS/MS and GC-MS, with limits of detection often in the low nanogram per gram (ng/g) range. The latter specifies that pollen is a better ecological indicator than honey, which is logical since pollen and nectar, the most important food sources for bees, are not contaminated with a wide variety of organic or inorganic substances. Banned pesticides were also found in pollen and beebread samples [26]. These were fenpropidin, methomyl, and permethrin. The above findings verify that the pesticide burden of pollen is greater than that of honey. Therefore, pollen, although much less consumed than honey, deserves more attention, as it is more susceptible to ecological pollution. As was shown in recent studies conducted by our group, pollen seems to represent better the degree of environmental pollution of the studied regions, especially by pesticides, and also by inorganic substances.

Heavy Metals

Heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) were found in honey samples from areas with high industrial activity, mining operations, or polluted water sources. Studies from India, China, and some Eastern European countries reported lead levels in honey exceeding the 0.1 mg/kg threshold established by the Codex Alimentarius [27]. ICP-MS and AAS were the most commonly employed analytical methods for heavy metals, offering high sensitivity and accurate quantification (Table *1*). Urban and industrial honeys consistently showed higher contamination levels than rural or organic counterparts. A few years back, maintaining a healthy nature has become a priority focus for European nations. As noted in the EEA report, "A considerable amount of the diseases prevalent in Europe are related to pollution related to the environment", which helps to understand how people are suffering due to the damage caused to the environment. Heavy metals are emitted into soil, air, and water by industries and farmers, transportation, and other human activities. This is why the levels of heavy metals in the nature, from which individuals draw resources, are noticeable and disturb both nature as well as humanity's health [28]. The concentration of heavy metals assessed in nearly all the honey samples was within acceptable limits, suggesting their cleanliness. Differences in the type of honey, soil composition,

precipitation levels, air temperature, plant species, and regional pollution all make it difficult to compare the quantities of heavy metals in honey samples to previously recorded data. Chronic exposure to low levels of lead and cadmium, even in trace quantities, can result in severe complications, including stunted mental development and disruptions to blood-related functions due to reduced hemoglobin production and shortened erythrocyte lifespan.

Antibiotics and Veterinary Drugs

Antibiotic residues such as tetracyclines, chloramphenicol, streptomycin, and sulfonamides were detected in honey samples, particularly from countries with less stringent apicultural regulation. Chloramphenicol, banned in food-producing animals in many countries, was detected in honey samples from Southeast Asia and South America [29]. Residue levels ranged from trace to several micrograms per kilogram, with LC-MS/MS and ELISA being the primary detection techniques. A significant number of samples failed to comply with international MRLs, posing both regulatory and public health concerns. Honey is a food of high nutritional significance and a food that has always been intended for human consumption. The production of honey and other beekeeping products from bees is dependent on the efficient functioning of this important sector since beekeeping directly influences the agricultural sector. The decrease in colony numbers has, among other reasons, been attributed to bee bacterial diseases, which commonly infect bees, including American foulbrood and European foulbrood and Nosema species disease [30]. In this sense, in apiculture, the prophylactic or therapeutic use of veterinary drugs is not uncommon and can lead to accumulation in bees and honey itself. If people consume treated honey, they could experience adverse effects, including allergic or hypersensitivity reactions, carcinogenicity, reproductive effects, and teratogenicity. The Commission Regulation (EU) lays down MRLs for the antibiotics in foodstuffs, but MRLs have not been set for api-products. The absence of harmonization of rules has resulted in some Member States defining recommended concentrations and performance limits. For this reason, the development of correct and precise analytical methodologies is essential. In recent years, the analysis of antibiotics in honey has resulted in the methods being developed across a large number of families, including aminoglycosides, amphenicols (novobiocin), lincosamides, macrolides, nitroimidazoles, quinolones, sulfonamides, tetracyclines, and nitrofurans.

Microbial Contaminants

Microbial contamination, while less commonly reported, was of particular concern in the context of infant botulism. *Clostridium botulinum* spores were detected in raw and unprocessed honey samples across multiple studies, including those conducted in the United States, Japan, and Egypt [31]. While rare, the presence of these spores underscores the importance of labeling honey with warnings against infant consumption (Table *2*). Other microbial contaminants included yeasts and molds, particularly in honey with high moisture content or improper storage conditions. Knowledge of the moisture and temperature conditions, which affect the growth of microorganisms in honey has been in use for some time as a basis for controlling spoiling. However, as new uses of honey and new technologies relating to honey develop, the necessity for additional microbiological data on honey is likely to become greater. Microorganisms in honey may affect quality or safety. Thanks to the natural properties of honey and control measures within the honey sector, honey is elucidated to contain few types and low levels of microbes. The microbes of concern in post-harvest product handling are those that occupy most honey (i.e., yeasts and spore-forming bacteria), those that indicate the sanitary or commercial quality of honey (i.e., coliforms and yeasts), and those which could cause human illness under certain conditions. Attribute to their natural source, potential sources of contamination are most likely pollen, honey bee's digestive system, dust, air, soil and nectar, all difficult to control. The same secondary (after-harvest) sources that typically contaminate any food product apply equally to honey. These include air, human (the food handler), cross-contamination, equipment, and buildings. Secondary (after-harvest) sources have suitably low levels of contamination by adhering to good manufacturing practices [32]. The microbes of concern in honey are predominantly yeasts and spore-forming bacteria. Total plate counts from various honey samples fluctuate from zero to tens to thousands per gram for unknown reasons. Almost all honey samples include detectable levels of yeasts. Many honey samples had yeast counts below the 100 colony forming units per gram threshold for yeast contamination, and yet yeasts are still potentially capable of growing in honey.

Adulterants and Physical Contaminants

Adulteration of honey with sugar syrups (e.g., rice, corn, cane) was widely reported, particularly in commercially available samples from certain exporters. Isotope ratio mass spectrometry (IRMS) and nuclear magnetic resonance (NMR) were increasingly used to detect syrup adulteration, as traditional sugar profile analysis often failed to differentiate added sugars [33]. Additionally, some studies reported the presence of physical contaminants such as wax particles, bee parts, and debris, usually attributed to poor handling or lack of filtration. The practice of honey adulteration occurs for various reasons, either for sweetness based on consumers' preferences or to gain profit by mixing cheap and low-quality honey for yield or profit of the expensive honey. According into our searching of numerous research databases such as Scopus, Web of Science, and Google Scholar, there are no or very few substantive studies on the toxicological impact of honey adulteration on human health to date [34]. Therefore, this review paper may

provide a starting point for scientists and researchers to explore commercial honey adulteration and the detriments of adulterated honey on human health. This review paper outlined several methods of adulteration and types of adulterants and also discussed the toxicological impact from honey adulteration to internal organs seen in various in vivo and in vitro studies.

Regional and Regulatory Trends

The review highlighted considerable regional disparities in contaminant levels and enforcement of standards. The European Union had the most rigorous monitoring programs and strictest MRLs, leading to higher detection rates due to advanced testing [35]. In contrast, several developing countries lacked standardized testing infrastructure, resulting in underreporting and potential market rejection of exported honey. Harmonization of international standards remains limited, with significant differences in detection thresholds, banned substances, and enforcement capacity [35]. In this way, sugars are added to honey through naturally occurring alterations that negatively affect consumers and the producers of pure honey and has consequences for the honey market. The other serious issues for honey production are unusual climate and severe weather conditions that lead to disruptions, causing great shortfalls in honey production. Changes in flowering time occur when conditions are lower than necessary temperature; heavy rain and wind have a substantial effect on bees, and in addition, there is a smaller area of the land that can be used to plant nectar plants, etc. In this context, the use of sugar or syrup to feed bees honey has shown to change the sugar profile of honey. Long-term feeding of bees syrup has been shown to change nectar sugars collected by bees. The other indirect method of honey adulteration is when unripe honey is used to replace capped ripe honey. Approximately, it takes 7-15 days for bees to brew thin nectar into capped ripe honey [36]. Ripe honey has a relatively high Baume rating, much less than 20% water content. For adulterated honey with starch or sucrose, a diastase will convert the doping food to a reducing sugar that could make the related value much lower. However, due to diastase content of natural honey based on different sources, establishing an accurate threshold value of diastase is therefore difficult, making it challenging to determine the threshold to use in the identification of honey authenticity.

Advances in Detection Technologies

Emerging technologies such as biosensors, surface-enhanced Raman spectroscopy, and portable field kits showed promise in enabling rapid, cost-effective, and in situ detection of honey contaminants. However, these technologies are still under development and have yet to match the sensitivity and specificity of laboratory-based methods like LC-MS/MS or ICP-MS [37]. Their integration into regulatory frameworks and field applications remains a key area for future development. In the past few years, RP-HPLC has become an essential tool in the isolation and characterization of proteins and peptides. The biotechnology sector depends on RP-HPLC considerably because it is routinely used as a detection method to characterize the proteins and peptides through the identification of the protein or peptide as well as impurities during structural characterization and functional characterization. When undertaking protein identification using mass spectrometry, the separation of digested proteomes and peptides is key to sample preparation, and RP-HPLC contributes substantially in this critical step. Since the principles for isolation are based on the features of hydrophobic substances and water, RP-HPLC is valuable in the large-scale purification of proteins. It is also part of the process that separates many different proteins and peptides during the research stage. There is a mechanism to separate and purify peptides according to their molecular sizes, which is called size-exclusion chromatography. Size-exclusion chromatography is one of the mechanisms that are being evaluated for the separation and purification of peptides, both as it represents an easy means to separate particles with variation in particle size, and a mechanism based on particle size for the separation and purification of peptides [38].

The findings of this review underscore the multifaceted nature of honey contamination, highlighting its global prevalence and the complex interplay between environmental factors, agricultural practices, and regulatory enforcement. The widespread detection of pesticide residues, heavy metals, antibiotics, and microbial agents across various regions demonstrates that no honey-producing area is immune to the risks associated with contamination [39]. Although honey is often perceived as a pure and health-promoting product, the data challenge this perception and call for a re-evaluation of production practices and food safety measures at both local and international levels. Pesticides emerged as the most frequently detected contaminants, reflecting the growing reliance on agrochemicals in intensive farming systems [40]. The detection of neonicotinoids in a majority of tested honey samples from industrialized regions suggests that even with regulatory restrictions in place, residue persistence and illegal use remain challenges. This underscores the need for stricter monitoring, greater transparency in pesticide application, and enhanced support for integrated pest management practices that reduce chemical reliance. Heavy metal contamination in honey appears closely tied to industrial development and environmental degradation. The detection of lead, cadmium, and arsenic in honey from regions with mining or poor waste management practices points to a broader issue of environmental stewardship. Since heavy metals are non-degradable and toxic even at low concentrations, their presence in honey raises significant public health concerns, particularly for consumers who rely on honey as a regular dietary supplement or therapeutic agent. Long-term exposure to contaminated honey could contribute to chronic

health conditions, including neurotoxicity and organ damage. Antibiotic residues reflect shortcomings in veterinary oversight and beekeeper education [41]. While antibiotics are essential tools in apiculture for disease control, their misuse or overuse leads to residues in honey that not only breach food safety standards but also fuel antimicrobial resistance-a growing global health crisis. Countries with less stringent veterinary regulations or inadequate residue monitoring are particularly at risk. The illegal use of banned substances like chloramphenicol in some regions also points to economic pressures driving non-compliant practices, reinforcing the need for international cooperation in regulating and harmonizing standards [42]. Microbial contamination, although less common, remains a critical issue due to its potential severity. The presence of *Clostridium botulinum* spores poses a rare but serious risk of infant botulism, justifying strict labeling regulations and public health education. Meanwhile, the growth of yeasts and molds in improperly stored honey indicates lapses in post-harvest handling and processing hygiene. These findings highlight the need for improved training and infrastructure for honey producers, particularly in rural and small-scale settings [43]. Adulteration, both deliberate and accidental, represents a different dimension of honey contamination-one driven more by economic incentives than environmental exposure. The mixing of honey with cheaper sugar syrups undermines consumer trust, devalues authentic products, and complicates regulatory enforcement. The sophistication of adulteration techniques has also increased, necessitating equally advanced detection methods such as NMR and IRMS [44]. Adulteration is particularly concerning for export markets, where non-compliance with purity standards can lead to trade bans and reputational damage for producing countries. From a methodological standpoint, the review shows that advanced techniques such as LC-MS/MS, GC-MS, ICP-MS, and ELISA are well-established tools for contaminant detection, offering high sensitivity and reliability. However, these techniques require significant technical expertise, costly equipment, and laboratory infrastructure-resources that are often lacking in lower-income countries [45]. This limitation creates disparities in testing capacity and enforcement. Therefore, future research and investment should prioritize the development of low-cost, portable, and user-friendly technologies, including biosensors and rapid test kits, that can empower local authorities and producers to conduct on-site screening. Regulatory frameworks vary widely between countries, with the European Union generally leading in terms of stringent MRLs, testing protocols, and traceability systems [46]. However, the lack of harmonized global standards creates confusion and hinders trade. For example, honey that meets MRLs in one country may be rejected by another, causing economic losses and undermining producer confidence [47]. Greater alignment between national and international food safety standards, such as those proposed by the Codex Alimentarius, would facilitate fair trade while ensuring consumer protection. One key insight from this review is that contamination often stems from factors outside the control of beekeepers, including environmental pollution, neighboring agricultural activity, and global supply chain dynamics [48]. Thus, addressing honey contamination requires a systems-level approach that integrates agricultural policy, environmental management, food safety regulation, and consumer education. Promoting organic and low-input farming systems, strengthening environmental monitoring, supporting sustainable beekeeping practices, and increasing transparency throughout the honey supply chain are essential steps toward long-term contamination mitigation.

Organ affected	Specific site of effect	Effects of various kinds
Skin	Outer layer & epidermis of skin	Used for non-healing wound
Mammary glands	Tumor cells	Manuka honey increases susceptibility of expression of proapoptotic proteins
Heart	Arteries	Phenolic acids & flavonoids compounds exhibit protective effects against CVD
Eye	Acting eye disease	Significant effect for increase in the tear breakup time and ocular disease
Large intestine	Colon of larger intestine	Various effects for immunostimulant, modulating the microbiota and suppressing pathogens
Liver	Jaundice	Significantly beneficial in the prevention of hepatic damage due to obstruction of the common bile duct
Bone	Reducing osteoclast cells	Formation and favor bone formation by osteoblasts

TABLE 2: Honey and their health benefits

Refer to [21]

Conclusions

Honey is contaminated after being affected by harmful substances like pesticides, heavy metals, and toxic antibiotics. Current modern analytical technologies exhibit significant sensitivity and specificity in the detection of these toxic compounds. This review has outlined the multifactorial sources of contamination and the health risks they pose, illustrating the complex relationship between honey production and its environmental and agricultural context. Future research should prioritize the development of low-cost,

rapid, and portable diagnostic tools with biosensors for onsite detection by small-scale beekeepers. There is also a clear need for longitudinal studies that monitor contamination trends over time and assess the impact of regulatory interventions and climate change on honey safety. Additionally, molecular-level investigations are also required for bee health and honey quality at the biochemical level. Furthermore, the growing issue of honey adulteration necessitates innovation in authenticity testing, especially through the use of advanced spectroscopic and isotopic techniques. Studies exploring the synergistic effects of multiple contaminants and their cumulative impact on human health are also critical. Finally, greater interdisciplinary collaboration between environmental scientists, apiculturists, toxicologists, food safety experts, and policymakers is essential to building integrated risk assessment models and formulating globally applicable safety guidelines.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Biswajit Patra, Surya Narayan Pradhan, Sibani Moharana

Acquisition, analysis, or interpretation of data: Biswajit Patra, Surya Narayan Pradhan, Sibani Moharana

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Critical review of the manuscript for important intellectual content: Biswajit Patra, Surya Narayan Pradhan, Sibani Moharana

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References

1. Usman AN, Fendi F, Nulandari Z, Agustin DI: Trends, key contributors, and emerging issues in honey and breast cancer: A bibliometric analysis from 2014 to 2024. F1000Research. 2025, 14:17. 10.12688/f1000research.159595.3
2. Zheng X, Xu Y, Huang Y, et al.: A focus on the Chinese stingless bee honey (Hymenoptera, Apidae, Meliponini): Exploring physicochemical parameters for establishing quality standards. Journal of Food Composition and Analysis. 2025, 137:106823. 10.1016/j.jfca.2024.106823
3. Ikegbunam NC, Walter OJ, Osayi EE: Evaluation of the floral diversity and physicochemical composition of honey procured from some markets in Anambra State, Nigeria. Journal of Applied Sciences and Environmental Management. 2025, 29:961-71. 10.4314/jasem.v29i3.35
4. Guo W, Dong S, Qian J, Wang K, Zhao Z: Estimation of carbon footprint of honey production: a case from China. Polish Journal of Environmental Studies. 2025, 34:1125-136. 10.15244/pjoes/187114
5. Poiša L, Adamovičs A, Teilāns AT: Honey production in Latvia. Sustainable Food Industry. 2025, 1:38-46.
6. Bellisai G, Bernasconi G, Carrasco Cabrera L, et al.: Modification of the existing maximum residue level for acetamiprid in honey. EFSA Journal. 2025, 23:e9300. 10.2903/j.efsa.2025.9300
7. Rani A, Verma S: Phytochemical composition, antioxidant, and antimicrobial potential of honey: a comprehensive review. International Journal of Plant and Environment. 2025, 11:10-19. 10.18811/ijpen.v11i01.02
8. Sari F: Predicting future opportunities and threats of land-use changes on beekeeping activities in Turkey. Environment, Development and Sustainability. 2024, 26:22389-2420. 10.1007/s10668-023-03557-7
9. Machado A, Toubarro D, Baptista J, Tejera E, Álvarez-Suárez JM: Selected honey as a multifaceted antimicrobial agent: review of compounds, mechanisms, and research challenges. Future Microbiology. 2025, 20:589-610. 10.1080/17460913.2025.2498233
10. Mara A, Mainente F, Soursou V, et al.: New insights on quality, safety, nutritional, and nutraceutical properties of honeydew honeys from Italy. Molecules. 2025, 30:410. 10.3390/molecules30020410
11. Rampazzo G, Nobile M, Carpino S, Chiesa L, Ghidini S, Gazzotti T, Panseri S: Detection of glyphosate, glufosinate, and their metabolites in multi-floral honey for food safety. Food Additives & Contaminants: Part A. 2025, 42:213-22. 10.1080/19440049.2024.2441752
12. Fakhri Y, Esfandiari Z, Mehri F, Ranaei V, Pilevar Z: The concentration of potentially toxic elements (PTEs) in honey: Global systematic review and meta-analysis and risk assessment. International Journal of Environmental Health Research. 2025, 35:37-55. 10.1080/09603123.2024.2341425
13. Paiano V, Breidbach A, Lörchner C, et al.: Detection of honey adulteration by liquid chromatography—high-resolution mass spectrometry: results from an EU coordinated action. Separations. 2025, 12:47. 10.3390/separations12020047

14. Ziemba EW, Maruszewska EW, Karmańska A, Aydın MN, Aydın Ş: Critical digital data enabling traceability for smart honey value chains. Journal of Computer Information Systems. 2025, 1-14. 10.1080/08874417.2025.2469092
15. Fan M, Pan C, Liu T, et al.: Quality evaluation of gallnut honey collected from different geographical areas of China. Journal of Apicultural Research. 2025, 1-14. 10.1080/00218839.2025.2483008
16. Vosoghi M, Yousefi S, Honarvar M: Physicochemical and sensory properties of honey powder from different climatic regions. Applied Food Research. 2025, 5:100843. 10.1016/j.afres.2025.100843
17. Faltus A, Pawłuszkiewicz K, Mikołajczak M, Korgiel M, Gaweł-Dąbrowska D: Benefits of honey supplementation for enhancing health and athlete performance. Quality in Sport. 2025, 40:59354. 10.12775/qs.2025.40.59354
18. Rocha GHAM, de Almeida MC, da Silva LL, Flores IS, Castiglioni GL, De Oliveira TF, Pereira J: Food-related properties and composition of cocoa honey (Theobroma cacao L.): An integrated investigation. Food Research International. 2025, 202:115694. 10.1016/j.foodres.2025.115694
19. Bilici F, Seren NA: A study on consumers' knowledge of distinguishing natural and organic honey. Turkish Journal of Agriculture - Food Science and Technology. 2025, 13:545-52. 10.24925/turjaf.v13i3.545-552.7182
20. Nganso BT, Ayalew W, Wubie AJ, et al.: Honey bee colony losses and causes during the active beekeeping season 2022/2023 in nine Sub-Saharan African countries. PLOS One. 2025, 20:e0322489. 10.1371/journal.pone.0322489
21. EFSA, Bellisai G, Bernasconi G, et al.: Modification of the existing maximum residue level for metalaxyl-M in honey. EFSA Journal. 2025, 23:e9296. 10.2903/j.efsa.2025.9296
22. Arany I, Czúcz B: Methods for Assessing the ecosystem service of honey provisioning by the European Honey Bee (Apis mellifera L.): a systematic review. Sustainability. 2025, 17:4533. 10.3390/su17104533
23. Bimbo F, Nico K, De Meo E: Assessing the quality and floral variety market value: a hedonic price model for honey. Sustainability. 2025, 17:3903. 10.3390/su17093903
24. Sitthisak C, Jomrit J, Chunglok W, Putalun W, Kanchanapoom T, Juengwatanatrakul T, Yusakul G: Effect of honey, as a natural deep eutectic solvent, on the phytochemical stability and anti-inflammatory activity of Eurycoma longifolia Jack. RSC Advances. 2025, 15:5252-263. 10.1039/d4ra05005c
25. Qiang HE, Wenjun HU, Jiong LI, Lu FE: Current status of honey export trade in China and comparative analysis of pesticide and veterinary residue limit standards at home and abroad. Journal of Agriculture. 2025, 15:72-81. 10.11923/j.issn.2095-4050.cjas2024-0027
26. Mahato R, Behera DK, Patra B, et al.: Plant-based natural products in cancer therapeutics. Journal of Drug Targeting. 2024, 32:365-80. 10.1080/1061186x.2024.2315474
27. Inaudi P, Garzino M, Abollino O, Malandrino M, Giacomino A: Honey: inorganic composition as possible marker for botanical and geological assignment. Molecules. 2025, 30:1466. 10.3390/molecules30071466
28. Pote CL, Shirsat DV, Mahadule PA, et al.: Biochemical, antioxidants, and mineral constituents of stingless bee honey. Frontiers in Sustainable Food Systems. 2025, 9:1546843. 10.3389/fsufs.2025.1546843
29. Chebli AI, Zergui A, Amziane A, Zebbiche Y, Abdennour S: Metals in honey, cow's milk and eggs in North-East Algeria and health risk. Food Additives & Contaminants: Part B. 2024, 18:55-64. 10.1080/19393210.2024.2414088
30. Hussein DY, Kadhem WM: Effect of honey on blood and biochemical parameters of rats with induced anemia. Agricultural Biotechnology Journal. 2025, 17:231-46. 10.22103/jab.2025.24690.1646
31. Nowak A, Muzykiewicz-Szymańska A, Perużyńska M, et al.: Assessment of in vitro skin permeation and accumulation of phenolic acids from honey and honey-based pharmaceutical formulations. BMC Complementary Medicine and Therapies. 2025, 25:43. 10.1186/s12906-025-04786-1
32. Ren C, Luo T, Qi S, et al.: Assessing the distribution and human health risks of cationic surface-active agents in honey from China. Journal of Hazardous Materials. 2025, 486:136956. 10.1016/j.jhazmat.2024.136956
33. Sahin Demirel AN: Investigating the impact of climate variables on the organic honey yield in Turkey using XGBoost machine learning. Journal of the Science of Food and Agriculture. 2025, 105:84-92. 10.1002/jsfa.13806
34. Hameed OM, Shaker OM, Ben Slima A, Makni M: Biochemical profiling and physicochemical and biological valorization of Iraqi honey: A comprehensive analysis. Molecules. 2024, 29:671. 10.3390/molecules29030671
35. Coppola F, Abdalrazeq M, Fratianni F, et al.: Rosaceae honey: antimicrobial activity and prebiotic properties. Antibiotics. 2025, 14:298. 10.3390/antibiotics14030298
36. Zhou X, Zhao W, Ye Z, Tang J, Zhang Y: Optimizing the methodology for antioxidant activity analysis of Manuka Honey. Foods. 2025, 14:1341. 10.3390/foods14081341
37. Galczynska M, Gamrat R, Puc M: Honey varieties vs metal and pesticide content - literature review and own research. Annals of Agricultural and Environmental Medicine. 2025, 32:9-19. 10.26444/aaem/197247
38. Zhang C, Zhou S, Wu C, Xu X, Zhu X: Evaluation of litchi honey quality in Southern China. Foods. 2025, 14:510. 10.3390/foods14030510
39. Zainuddin AN, Mustakim NN, Rosemanzailani FA, Fadilah NI, Maarof M, Fauzi MB: A comprehensive review of honey-containing hydrogel for wound healing applications. Gels. 2025, 11:194. 10.3390/gels11030194
40. Sanzhara RA, Kucher SO, Pastushok RS, Mykolaichuk LP, Gutyj BV, Mylostyvyi RV: The efficiency of feed paste consumption affects wintering success and subse-quent colony development in honey bees. Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies. 2025, 27:52-56. 10.32718/nvlvet-a10208
41. dos Santos Silva A, Maciel MC, de Oliveira AA, de Oliveira TF: Evaluation of the content of macro and trace elements and the geographic origin of honey in North Brazil through statistical and machine learning techniques. Journal of Food Composition and Analysis. 2024, 128:106050. 10.1016/j.jfca.2024.106050
42. Besharati M, Far MN, Azhir D, Palangi V, Lackner M: Evaluation of physicochemical properties of honey produced in East Azerbaijan Province, Iran. Applied Food Research. 2025, 5:100933. 10.1016/j.afres.2025.100933
43. Li AR, Johari SA, Abidin NH, Isa MM, Wahab HA, Mohtar M: Physiochemical characterization and antibacterial properties of a honey-like extract from Averrhoa carambola fruits. Journal of Food Science and Technology. 2025, 1-9. 10.1007/s13197-024-06185-9
44. Roy K, Majie A, Jha B, Chatterjee A, Lim WM, Gorain B: Comparative physicochemical, microbiological, pharmacological, and toxicological evaluations of different varieties of honey targeting wound repairment. Biocatalysis and Agricultural Biotechnology. 2025, 65:103544. 10.1016/j.bcab.2025.103544

45. Awolu OO, Ikumawoyi SO, Aluko BO, Lawal OM, Fagbemi TN: Impact of geographical variations on the physicochemical properties, antioxidant activities and viscosity of honey from Nigeria. IPS Journal of Nutrition and Food Science. 2025, 4:283-92. 10.54117/ijnfs.v4i1.70
46. Anwar A, Faiz MA, Hou J: Effect of honey concentration on the quality and antioxidant properties of probiotic yogurt beverages from different milk sources. Applied Sciences. 2025, 15:2210. 10.3390/app15042210
47. Patra B, Pradhan SN: Contamination of honey: a human health perspective. Health Risks of Food Additives - Recent Developments and Trends in Food Sector. 2024, 10.5772/intechopen.109613
48. Patra B, Meena R, Rosalin R, Singh M, Paulraj R, Ekka RK, Pradhan SN: Untargeted metabolomics in piper betle leaf extracts to discriminate the cultivars of Coastal Odisha, India. Applied Biochemistry and Biotechnology. 2022, 194:4362-376. 10.1007/s12010-022-03873-0