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Review Article

Honey Adulteration and Its Consequences on Quality, Health, and the Economy, Along With the Analytical Techniques Used for Its Detection

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Abstract

Honey is one of the most widely consumed natural food materials in the world due to its nutritional, medicinal, and economic importance. However, adulteration of honey with cheap sweeteners such as invert sugar, high fructose corn syrup, and sugar syrups, has become a major global concern. Adulteration not only affects honey quality and authenticity but also poses serious health and economic risks to consumers and producers. Adulteration can elevate consumers' blood glucose levels, potentially contributing to diabetes, obesity, abdominal weight gain, hypertension, and higher blood lipid levels. The various analytical techniques, including liquid chromatography-mass spectrometry, nuclear magnetic resonance, and isotope ratio mass spectrometry, have been employed for the detection of adulterants. Strengthening of food regulatory systems and awareness among consumers and beekeepers are vital to ensure the purity of honey and protect the global honey market. A review is essential to consolidate information on the extent of adulteration and techniques employed for its detection across regions and markets. This paper reviews honey adulteration practices, detection methods, and tools used for their detection, and outlines their impacts on human health, trade, and consumer trust and summarizes analytical methods for detection, improves monitoring protocols and discusses emerging technologies such as UV-Vis-NIR spectroscopy and Artificial Intelligence (AI), Thermal Imaging and AI, Hyperspectral Imaging and Chemometrics.

Categories: Food processing, Food quality, Food security and sustainability

Keywords: honey, adulteration, sugar syrup, authenticity, detection, health impact

Introduction And Background

Honey is a natural substance produced by honeybees (*Apis* spp.) that contains a complex mixture of carbohydrates, enzymes, amino acids, minerals, antioxidants and vitamins [1,2]. Due to its nutritional and therapeutic value and wide availability, honey has been consumed since ancient times and is an important economic product for beekeepers. However, increasing market demand and high commercial value have led to widespread adulteration activities [3].

Adulteration of honey is defined as the intentional addition of foreign material into honey, such as sugar syrups or artificial sweeteners, to increase volume and reduce cost [4]. However, honey is frequently adulterated for economic gain. Adulteration includes the addition of cheaper sweeteners, dilution with water, use of industrial-grade sugars, or manipulation of bees' feeding to increase yield [5]. Such adulteration affects honey's authenticity, therapeutic properties, and market value. The high demand for honey, combined with financial incentives, makes it highly vulnerable to fraud

[6]. Hence, detection and prevention of honey adulteration have become global priorities in food safety. This fraudulent practice compromises the authenticity, safety and worldwide, consumption of honey as a natural sweetener, a spread, and a key ingredient in baking and processed foods and the dietary pleasure and medicinal efficacy of honey [7]. Moreover, adulterated honey can have long-term health implications, including metabolic disorders and allergies [8]. Thus, understanding the nature, detection, and impact of honey adulteration is significant to ensure safe food and customer protection. Honey adulteration is not merely a food fraud issue. It is a multilayered supply chain problem involving chemical mimicry, technological evasion, and regulatory gaps. To detect these, various honey adulterations detection techniques are available, which include physicochemical Tests, isotope analysis, Spectroscopic and Chromatographic Techniques, Melissopalynology, and DNA Analysis. These methods have significantly improved adulteration traceability; however, effective enforcement and increased awareness are equally important for combating honey adulteration. Traditional food safety approaches are not adequate for evaluating Economically Motivated Adulteration (EMA) or for preventing deliberate food adulteration. Therefore, avoidance of EMA requires a holistic and systems-based approach that takes advantage of multiple data sources and disciplines [9]. These techniques have many limitations, and fraudsters are constantly adapting to existing revealing methods. The methodology used is focused on a limited number of indicators, which are insufficient to detect the purity of honey. It is no longer possible to focus on one indicator only, but a wide range of quality indicators need to be determined in order to detect honey adulteration [5]. To overcome these issues, new generation technologies such as UV-Vis-NIR spectroscopy and Artificial Intelligence (AI), Thermal Imaging, and Hyperspectral Imaging and Chemometrics have been utilized. But these advanced methods are much costlier, difficult to access, and lack universal detection protocols.

This manuscript summarizes current knowledge of how adulteration impacts quality, highlights health concerns associated with adulterated honey, describes analytical techniques along with their limitations, economic consequences, and new emerging technologies used in the detection of adulterated honey. Understanding the economic consequences can motivate stricter regulations and support policies to protect authentic honey markets.

Review

Types and sources of honey adulteration

Honey adulteration occurs at different stages of production and marketing. Direct adulteration, indirect adulteration, mislabeling fraud, and ultra-processing practices exploit the chemical similarity between natural honey sugars (fructose, glucose) and industrial syrups, making detection increasingly complex. Each honey type has a unique isotopic signature, pollen profile, and spectral fingerprint. Adulteration disrupts this fingerprint, reducing traceability and authenticity verification. The sources of honey adulteration are given in Figure *1* and further details of this diagram are discussed in the text below.

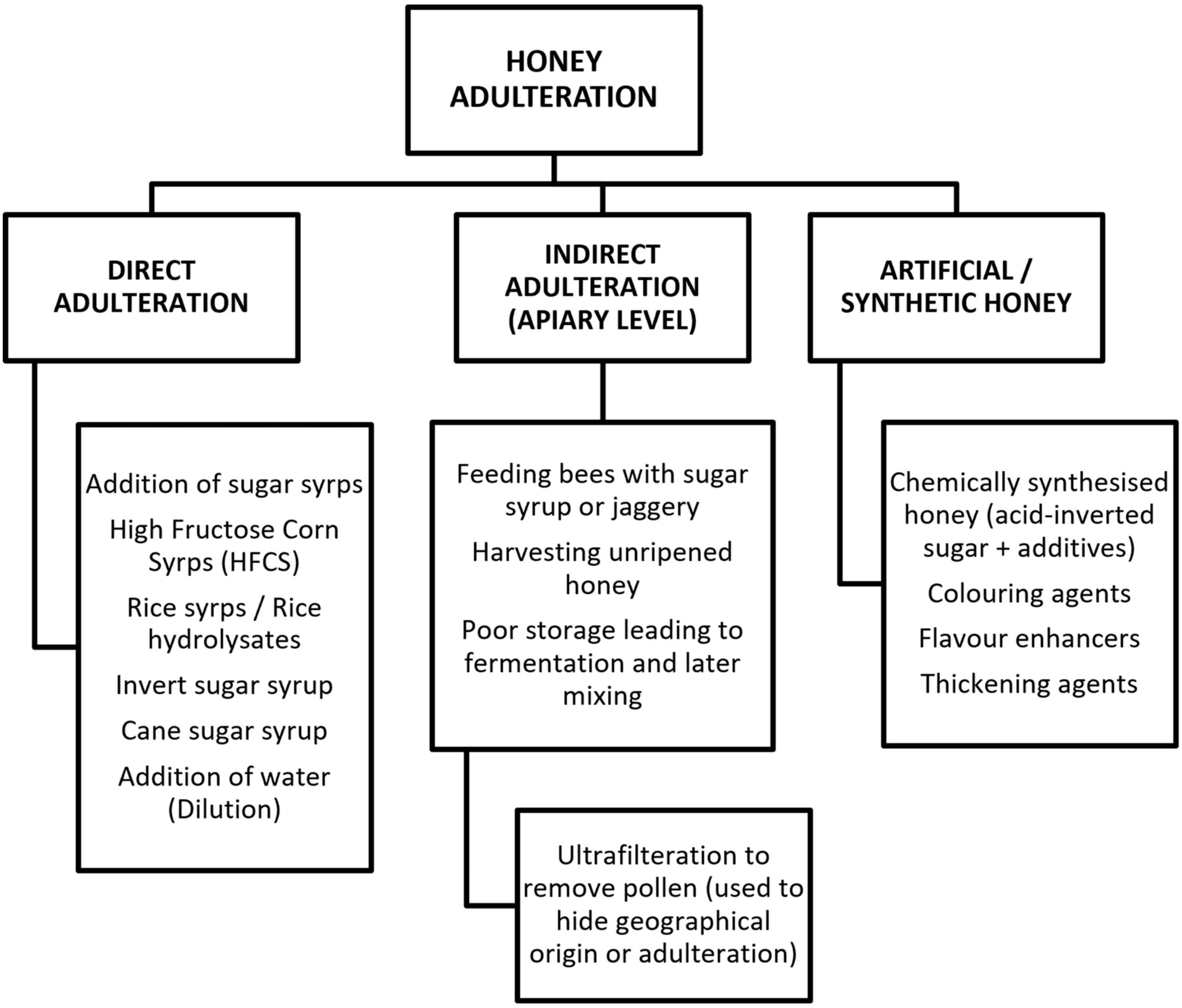

FIGURE 1: Sources of Honey Adulteration

Direct Adulteration

It is the addition of exogenous sugars (corn, rice, cane syrups rich in C4 sugars). Adulterants are often added to honey because of their low cost and similar composition. While these substances can mimic honey, they are harmful to bee colonies, as they can negatively impact factors like the formation of hydroxymethylfurfural (HMF), pH levels, and overall colony health. Additionally, the quality of the honey is compromised. It involves adding of cane sugar syrup, corn syrup, glucose, or invert sugar after honey extraction. These adulterants mimic natural honey sugars, making detection difficult. The common adulteration activities are adding high-fructose corn syrup (HFCS), rice syrup, cane sugar syrup, beet sugar syrup, and invert sugar syrup [10]. These syrups imitate honey's carbohydrate composition and are often difficult to detect using basic tests.

Water addition reduces viscosity and increases the potential for fermentation, degradation, and microbial growth. Honey with moisture above 20% is generally considered adulterated or improperly processed [11]. Artificial sweeteners such as aspartame, saccharin, or acesulfame-K are used to enhance sweetness while reducing cost. These compounds do not naturally occur in honey, and their detection indicates adulteration. Owing to their distinct chemical structures and physicochemical properties, they can be accurately identified and quantified through chromatographic analysis [12]. Colorants (caramel), thickeners (starch, gelatin), and artificial flavors may be added to mimic the sensory characteristics of natural honey [5].

Indirect Adulteration

This form of adulteration occurs when honeybees are fed sugar syrups or molasses during nectar flow or periods of nectar scarcity, resulting in alterations to the intrinsic composition of honey. Consequently, the produced honey becomes compositionally similar to honey adulterated with exogenous sugars, making its detection particularly challenging. Such feeding practices can modify the natural sugar profile and other quality attributes of honey, especially when artificial syrups are provided without appropriate management practices [13].

Processing

Adulteration is not limited to the addition of foreign substances; it also includes processing and labeling practices that misrepresent the quality or identity of honey. Excessive heating, often employed to delay crystallization and improve visual appearance, can degrade the natural quality of honey by reducing enzyme activity, increasing HMF content, and diminishing heat-sensitive bioactive compounds. Similarly, mislabeling the botanical or floral origin of honey (e.g., marketing multifloral honey as monofloral honey) constitutes economic adulteration because it provides false information regarding the product's identity and origin. Such practices violate food regulatory standards, as they deceive consumers and compromise the authenticity, traceability, and quality of honey [14,15].

Methods for detection of adulteration

Detection of honey adulteration requires robust, sensitive, and reliable analytical methods because adulteration practices have become increasingly advanced. Advances in analytical chemistry have led to several reliable techniques for detecting honey adulteration:

Physicochemical Tests

Detecting honey adulteration relies heavily on physicochemical parameters that reflect honey's natural composition. Adulterants such as sugar syrups, molasses, invert sugar, jaggery syrup, and starch-based additives alter these parameters in measurable ways.

Tests such as moisture content, electrical conductivity, HMF level, diastase activity, sucrose level, and acidity provide preliminary indications of honey purity [11,16]. The following physicochemical tests are widely used to evaluate honey authenticity.

Moisture Content: It indicates dilution of honey with water or early harvesting. Pure honey typically contains <20% moisture, depending on botanical origin. Adulterated or immature honey contains >20% moisture levels. Increased moisture levels are associated with sugar syrup addition and improper processing. It can be measured using a digital refractometer or Abbe refractometer, based on the refractive index. Low moisture (<15%) can also occur when honey is heated excessively [1].

pH and Free Acidity: Natural honey is mildly acidic (pH 3.2-4.5) due to organic acids like gluconic acid, which is produced through the enzymatic oxidation of glucose by glucose oxidase. This acidic environment contributes to the characteristic flavor, microbial stability, and extended shelf life of honey by inhibiting the growth of spoilage microorganisms. Adulteration disrupts acidity levels. Lower acidity suggests sugar or rice syrup adulteration while abnormally high acidity may occur due to fermentation. pH can be checked with a pH meter and free acidity with titration with NaOH [17]. Although pH and free acidity are valuable physicochemical indicators of honey quality, they should be interpreted alongside other analytical parameters because natural variations in botanical origin and geographical source can also influence these characteristics.

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Electrical Conductivity (EC): EC reflects ash and mineral content. Addition of plant syrups or sugar solutions alters EC values. Pure honey typically shows conductivity 0.2-0.8 mS/cm while adulteration of honey with honeydew possess higher EC. Lower value of EC significantly indicates adulteration with sugar syrup. It is measured using a conductivity meter in a 20% honey solution [18].

Ash Content: Ash represents the mineral content, and its normal range in pure honey is generally 0.02-0.3%. Higher ash content indicates honey rich in honeydew, mineral-rich adulterants, molasses, or jaggery syrup. The presence of lower ash content reflects diluted or artificially inverted or refined sugar syrup. It is a supporting indicator when combined with sugar profile (sucrose/reducing sugars), HMF levels, and enzyme activity. It is detected by dry ashing at 600°C in a muffle furnace [3].

Reducing Sugars (Glucose + Fructose): Pure honey contains >65% reducing sugars. Adulteration alters sugar ratios. Low reducing sugar indicates addition of sucrose syrup. These can be detected with Lane-Eynon titration or high-performance liquid chromatography (HPLC) [19].

Sucrose Content: Pure honey has <5% sucrose. Increased sucrose suggests addition of cane sugar or incomplete natural inversion. High sucrose (>5%) indicates cane sugar or jaggery adulteration. It is detected with polarimetry or HPLC [20].

HMF Content: It is an indicator of heat treatment and storage. HMF forms when fructose degrades during heating or prolonged storage. HMF >40 mg/kg indicates overheating or addition of inverted sugar. Very low HMF may also indicate fresh adulteration. The Winkler method and spectrophotometry are used to detect HMF [11].

Diastase Activity (Enzymatic Index): Diastase (amylase) naturally present in honey and decreases with heating or adulteration. Diastase number <8 indicates adulteration or thermal degradation. The Schade or Phadebas method is used for its detection [21].

Proline: Proline is the major amino acid in pure honey. Pure honey usually contains >180 mg/kg. High proline content indicates natural, unadulterated honey while low proline content in honey indicates sugar syrup adulteration and immature/uncapped honey. In the proline test, deep red color detects pure honey, while a faint color indicates adulterated honey. The proline test is usually combined with other tests (like sucrose content and the HMF test) for confirmation. It is detected with a spectrophotometric ninhydrin assay [22].

Specific Optical Rotation: Monofloral honey typically shows negative optical rotation (usually around −20° to −30°). Natural honey possesses high fructose content (normal composition). Positive rotation suggests sugar or starch syrup adulteration. The addition of cane sugar-based syrups alters optical behavior. A polarimeter reading on a honey solution detects optical behavior [23].

Color Measurement (Pfund Scale): Honey color (dark, amber, light) depends on floral source, mineral content, storage, and processing floral source but also changes when adulterated. The Pfund Scale expresses color in millimeters (mm Pfund) and confirms the color grade. It is helpful along with other physicochemical test to detect the purity of honey. Irregular color changes may signal caramel addition, molasses mixing, and excessive heating. Reading the absorbance at 560 nm and converting to Pfund values [24].

Viscosity: It is the thickness or resistance to flow of honey. Honey viscosity depends on moisture, sugar composition, and temperature. Lower viscosity indicates dilution with syrup while higher viscosity may indicate adulterants like jaggery syrup. Pure honey has a thick, slow-flowing consistency, forms a continuous thread when poured, and does not spread quickly. Adulterated honey has a thin, watery consistency, flows rapidly, breaks easily while pouring and indicates low viscosity. It can be detected with a Brookfield viscometer [24].

Density and Specific Gravity: In pure honey, normal specific gravity (SG) range is 1.35-1.40 g/mL. A lower value of SG in honey indicates dilution with water, addition of sugar syrup, or high moisture content. It must be observed at a standardized usually 20°C; otherwise, it affects readings. Density decreases when adulterated with water or sugar syrups [25].

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Ash Alkalinity: Ash alkalinity varies with floral source and geographic origin. It is a supportive test, not confirmatory alone. Its normal range is 0.1-0.5%. Abnormal alkalinity indicates mineral-rich adulterants or contamination. Below the normal range of ash alkalinity indicates dilution of honey with sugar syrup (low minerals) and artificial honey while above the normal range indicates contamination with dust, soil, processing impurities, or mineral-rich substances [26].

These various physicochemical methods are significant to analyze the purity of honey. The limitations of these include low specificity and they are easily bypassed by sophisticated adulterants. This review shows that these physicochemical tests may overlap between natural and adulterated honey because natural variation (botanical origin, processing, storage) can produce the same parameter ranges as mild adulteration.

Isotope Analysis

Isotope ratio mass spectrometry (IRMS) distinguishes between C_3 plant-based nectar and C_4 sugar adulterants. Stable isotope analysis especially stable carbon isotope ratio analysis is an important scientific method used to verify honey authenticity and identify adulteration, including the addition of C_4 plant-derived syrups such as corn or sugarcane [27,28]. IRMS distinguishes authentic honey from cane- or corn-syrup-adulterated honey based on $\delta^{13}C$ isotopic ratios. The $\delta^{13}C$ value of authentic honey ranges from −23.5% to −25.5% [6]. Isotope analysis is highly reliable for cane and corn syrup detection but cannot detect C_3 adulterants such as rice syrup.

Spectroscopic and Chromatographic Techniques

Fourier transform infrared spectroscopy, nuclear magnetic resonance (NMR), HPLC, and liquid chromatography-mass spectrometry are powerful tools for identifying sugar adulterants at trace levels [29]. NMR is highly effective for detecting C_3 and C_4 plant-derived syrups [6]. Gas Chromatography-Mass Spectrometry is used to detect volatile profiles and additives such as artificial flavorings [12]. Raman Spectroscopy is useful for identifying specific functional groups in adulterants [30]. HPLC is used for profiling sugars, organic acids, and identifying adulterants [31]. The chromatographic techniques have high sensitivity and specificity but are expensive, time-consuming, and require skilled personnel. The spectroscopic techniques create a “spectral fingerprint” of honey. They are rapid and non-destructive and can detect subtle compositional deviations. The limitation of these techniques is that they require chemometric models and large reference databases.

Melissopalynology and DNA Analysis

Melissopalynology and DNA barcoding are used to confirm floral and geographical origin of honey [32,33]. DNA barcoding is emerging as a reliable authentication tool.

Emerging Technologies include: chemometric modeling, machine learning-based spectral analysis, electrochemical sensors, and metabolomic fingerprinting [30]. These approaches are promising for rapid and field-level detection.

Implications of Honey Adulteration

Honey adulteration directly affects honey’s chemical, physical, and sensory properties. It reduces nutritional value (loss of bioactive compounds, phenolic compounds, enzymes, antioxidants), alters physicochemical parameters such as sugar profile, viscosity, moisture content, and HMF levels, and diminishes authenticity markers critical for labeling and consumer trust. Altered sugar ratios affect crystallization and viscosity while elevated HMF levels indicate overheating or sugar addition.

The consequences of honey adulteration are shown in Figure *2*. The components of this diagram are elaborated in the following sections.

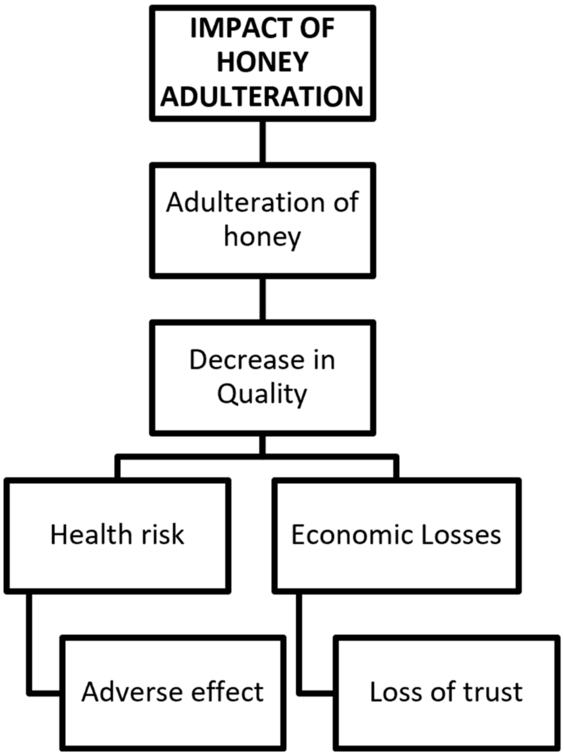

FIGURE 2: Impact of Honey Adulteration

Impact on Quality and Authenticity

Adulteration alters honey's natural composition, reducing enzymatic activity (e.g., invertase, diastase) and antioxidant capacity [34]. It also distorts flavor, aroma, and color characteristics. It reduces therapeutic value (wound healing, antimicrobial effects). Adulterated honey demonstrates decreased enzyme activity, reduced antioxidant and antimicrobial properties, and altered sensory qualities [13]. Proline, pH, and moisture content levels decline with increasing amounts of molasses, sugar, banana adulterants, and melted candy. Overall, sugar composition serves as an important indicator for identifying honey adulteration [35].

Health Implications

Consuming adulterated honey may pose several health risks. High levels of added sugars contribute to obesity, diabetes, and cardiovascular issues. Industrial syrups may introduce contaminants, pesticide residues, or harmful additives. Infants, immunocompromised individuals, and people with specific metabolic conditions are particularly at risk. Natural honey offers several health benefits, including reducing low-density lipoprotein (LDL) and total cholesterol levels in healthy individuals. In contrast, consuming 3-20% dietary fructose has been shown to increase LDL and total cholesterol by 11% and 9%, respectively. Therefore, adding sugar to honey can pose significant health concerns [36]. Adulteration poses serious health risks to consumers, which can contribute to high blood pressure and an altered lipid profile, higher blood sugar concentrations, obesity, and abdominal weight gain. The utilization of adulterated honey potentially causes obesity, diabetes, and gastrointestinal disorders due to excess refined sugar intake [37]. In addition, chemical residues from processing may cause allergic or toxic reactions. Although many added syrups are food-grade, chronic consumption of adulterated honey increases glycemic load, enhances the risk of obesity and metabolic disorders, and reduces medicinal benefits [12]. Industrial-grade syrups may contain chemical contaminants harmful to health. Certain adulterants (e.g., syrups, contaminants) can cause liver and kidney damage. Histological studies link adulterated honey to organ toxicity and renal dysfunction.

Economic and Trade Impact

Honey adulteration undermines the beekeeping and food industry. It imposes regulatory and trade burdens on beekeepers and farmers by increasing costs for testing and certification and causing trade disputes due to failed authenticity checks. It causes a loss of consumer confidence and market value of authentic honey. Unfair competition for genuine producers affects livelihoods and rural economies. It strains regulatory agencies due to testing and enforcement costs. Understanding these economic consequences can motivate stricter regulations and support policies to protect authentic honey markets.

Honey and bee products improve sustainable incomes for farmers [38]. Adulteration undermines the integrity of the honey market, leading to financial losses for genuine producers and loss of consumer trust [39]. International honey trade has faced multiple rejections due to regulatory violations of purity principles, affecting export revenues. Adulteration causes significant losses to genuine beekeepers, distorts market competition, and affects export standards [2]. Today, honey adulteration causes significant economic losses, not only by reducing the quality of honey but also by making it more challenging to market genuine honey. The majority of the honey available in the market consists of caramelized sucrose lacking nutritional value. As a result, the widespread presence of such adulterated products has led consumers to lose confidence in the true nutritional benefits of genuine honey [37]. It impacts the beekeeping sector by reducing profitability, discouraging apiculture, and threatening pollination services and biodiversity indirectly

Regulatory Standards and Prevention

Honey adulteration creates a negative feedback loop affecting producers, regulators, and consumers. Agencies like Food Safety and Standards Authority of India (FSSAI) and the Codex Alimentarius Commission [11] define quality parameters for authentic honey. These include limits for HMF (<40 mg/kg), a minimum diastase number (8), and the absence of added sugars. The Codex Alimentarius Standard (CODEX STAN 12-1981) specifies acceptable limits for major honey quality parameters such as moisture, HMF, sucrose, and enzyme activity [11]. National standards like FSSAI (India) also regulate honey purity. Preventive strategies include promoting traceability through QR-coded packaging, third-party testing using advanced analytical tools, beekeeper training on ethical honey production, and consumer awareness campaigns on identifying pure honey.

Emerging Technologies and Future Scope

Emerging analytical technologies combined with AI are expected to revolutionize honey authentication by enabling rapid, accurate, and non-destructive detection of adulteration. Future research should focus on developing portable and cost-effective spectroscopic devices integrated with machine learning algorithms for real-time, on-site honey authentication throughout the supply chain. UV-Vis-NIR spectroscopy and AI: Researchers in Bangladesh have developed a rapid, non-destructive method to detect honey adulteration using UV-Vis-NIR spectroscopy paired with machine learning. Their findings could protect consumers and support food quality enforcement. The method captures absorption spectra across 200-900 nm, allowing detailed chemical profiling and identification of adulterants like corn syrup and caramel color [40]. Thermal imaging and AI: It is a novel approach for classifying levels of honey adulteration. It detects adulteration based on heat signatures and composition differences. It provides high classification accuracy even at low adulteration levels [41]. Hyperspectral Imaging and Chemometrics: It uses spatial and spectral data. It enables quantification of adulteration levels. Detection of adulteration is based on hyperspectral imaging technology, LIBSVM, and PLSR models for qualitative and quantitative analysis [42].

Another important research direction is the establishment of comprehensive global spectral and chemical fingerprint databases representing authentic honey from different botanical and geographical origins. Such databases would enhance the robustness and generalizability of AI-based authentication models while minimizing false-positive and false-negative classifications. The development of multimodal analytical platforms that combine spectroscopic, chromatographic, isotopic, and metabolomic data is expected to provide higher sensitivity and specificity than individual techniques. Future studies should also emphasize the standardization and validation of AI-assisted analytical methods according to international regulatory guidelines to facilitate their routine adoption by food testing laboratories and regulatory agencies. In addition, cloud-based platforms and Internet of Things (IoT)-enabled sensors could enable continuous monitoring of honey quality across production, processing, storage, and distribution. The integration of blockchain technology with AI-driven authentication systems may further improve traceability, transparency, and consumer confidence by providing tamper-proof records of honey origin and quality. Overall, the convergence of spectroscopy, imaging technologies, chemometrics, AI, and digital traceability systems is expected to establish rapid, automated, and highly reliable honey authentication frameworks that will strengthen food safety, reduce economic fraud, and enhance consumer trust in the global honey market.

Conclusions

Honey adulteration remains a significant challenge to food authenticity, consumer safety, and global trade. Increasingly sophisticated adulteration practices highlight the need for advanced analytical methods and strict regulatory monitoring. Modern detection techniques have improved adulteration traceability, but enforcement and awareness are equally crucial. Fraudsters are continuously adapting to existing detection methods. Collaborative efforts among researchers, regulatory bodies, and honey producers are essential to ensure that honey reaching consumers remains pure, natural, and beneficial to health. Adoption of combined physicochemical, spectroscopic, chromatographic, and isotope-based techniques is essential to ensure honey authenticity. Consumer awareness, quality enforcement, and improved traceability can significantly reduce adulteration and protect the apiculture industry. Therefore, it is emphasized that periodic training sessions for stakeholders on detecting adulteration should be conducted to help prevent the presence of adulterated honey in the market. Although there are various techniques available to analyze the quality of honey, these have their own limitations. Further advanced methods are much costlier, difficult to access, and lack of universal detection protocols. Therefore, more research is needed to overcome the negative loop, develop quality evaluation techniques, and also understand the functioning of new emerging technologies. Thus, future research must focus on global authentication databases and multi-method approaches, consumer protection, and industry sustainability.

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: Rakesh Kumar, Sonu Kumari, Lalita Panwar, Abhinav Saxena

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Drafting of the manuscript: Rakesh Kumar, Sonu Kumari, Lalita Panwar, Abhinav Saxena

Critical review of the manuscript for important intellectual content: Rakesh Kumar, Sonu Kumari, Lalita Panwar, Abhinav Saxena

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Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following:

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Data Availability Statements

Data sharing is not applicable. This work is theoretical; no datasets were generated or analyzed.

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