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Review Article

The Toxic Impact of Honey Adulteration

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ABSTRACT

The nutritional, antibacterial, and antioxidant qualities of honey, a natural sweetener and medicinal food, are well known. Its purity has been weakened by extensive adulteration, raising serious public health issues. In order to imitate real honey, adulteration entails adding less expensive sweeteners like high-fructose corn syrup, glucose, cane sugar, or rice syrup in addition to using preservatives, colorants, and antibiotics. These methods change the chemical makeup of honey and add dangerous materials such pesticide residues, heavy metals, and hydroxymethylfurfural (HMF). Long-term ingestion of tainted honey has been linked to liver damage, metabolic problems, antibiotic resistance, and cancer. Adulteration identification has increased thanks to analytical detection employing cutting-edge methods including FTIR spectroscopy, HPLC, NMR, and isotope ratio mass spectrometry. Studies conducted worldwide have shown concerning rates of adulteration, which damage genuine beekeepers financially and erode customer trust. Quality requirements are provided by regulatory frameworks as the EU Honey Directive, FSSAI, and Codex Alimentarius, however enforcement is uneven. To stop adulteration, it is essential to implement traceability technologies like Blockchain, increase public awareness, and fortify monitoring systems. The toxicological hazards, analytical detection developments, and international laws pertaining to honey adulteration are highlighted in this study, along with the pressing need for more stringent oversight and consumer education to maintain the safety and authenticity of honey.

INTRODUCTION

For millennia, people have valued honey, a natural product made by *Apis mellifera* and other bee species, for its nutritional and therapeutic benefits. It has a complex blend of organic acids, carbohydrates, enzymes, amino acids, vitamins, minerals, and bioactive chemicals that give it antibacterial, antioxidant, and wound-healing qualities, among other medicinal benefits[1]. Honey is often seen as a sign of health and purity, but

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because to its limited supply and rising demand, it has been a popular target for commercial adulteration[2]. According to the Food and Agriculture Organization (FAO), honey is one of the top five most contaminated foods in the world. In addition to misleading customers, adulteration includes potentially dangerous ingredients that jeopardise the safety of food[3]. In addition to artificial preservatives, antibiotics, and colorants added to simulate natural qualities, these adulterants may include sugars made from corn, cane, rice, or beetroot. Through prolonged toxicity, allergenicity, and metabolic imbalance, such activities compromise the nutritional value of honey and provide health risks. Toxicologically speaking, tainted honey may contain heavy metal or pesticide residues received from contaminated floral sources, as well as hydroxymethylfurfural (HMF), a carcinogenic substance created during excessive heating or sugar inversion[4]. The content of pure honey, adulteration strategies, toxicological effects, analytical detection methods, case studies that have been documented, regulatory frameworks, and public health consequences are all covered in detail in this paper. In order to guarantee the safety and authenticity of honey, it also offers insights into potential future research and policy areas[5].

Composition of Pure Honey:

- The trace amounts of sucrose, maltose, amino acids, organic acids, vitamins (B-complex, vitamin C), minerals (potassium, calcium, iron), and enzymes (invertase, glucose oxidase, and catalase), pure honey is a supersaturated mixture of sugars, mostly fructose (38%) and glucose (31%) [6].

- Its low water activity and pH (3.2–4.5) prevent the development of microorganisms. Flavonoids and phenolic substances add to its antioxidant potential.

- Electrical conductivity and moisture levels are essential for determining purity, whereas pollen content indicates the flower origin. Exogenous sugars, high HMF levels, and artificial additions are absent from real honey[7].

Types and Methods of Honey Adulteration:

1. Adding inexpensive sweeteners like corn syrup, cane sugar, or jiggery syrup to boost volume is known as "direct adulteration."
2. Indirect adulteration is the process of mixing honey from several areas or feeding bee's sugar syrup while nectar is flowing[8].
3. Sophisticated Adulteration: To avoid detection, use artificial honey or syrups that are isotopically identical.
4. Chemical adulteration is the practice of adding colorants, antibiotics, and preservatives to products in order to prolong their shelf life[9].
5. Thermal Manipulation: When viscosity is decreased by overheating, a high HMF is formed[10]. **Toxicological Impact of Adulteration:**

- Overheating produces hydroxymethylfurfural (HMF), which is associated with liver damage and possible carcinogenicity.

- Heavy Metals: Neurotoxicity and renal failure are caused by lead, cadmium, and arsenic found in polluted equipment.

- Antibiotic Residues: Tetracycline and chloramphenicol residues encourage allergic responses and antibiotic resistance[11].

- Pesticide residues can be hepatotoxic and alter hormones.

- Metabolic Disorders: Sugars with high glucose content increase the glycaemic load, which leads to diabetes and obesity.
- Microbial Contamination: Adulteration raises the possibility of Clostridium botulinum spores, which might be harmful to a baby's health[12].

Analytical Detection Methods for Adulteration:

1. Determine the chemical fingerprints and composition of sugar using FTIR and Raman spectroscopy[13].
2. Measure sugars, HMF, and other contaminants using HPLC and GC-MS.
3. Plant-origin sugars may be distinguished from synthesised ones using isotope ratio mass spectrometry (IRMS).
4. NMR Spectroscopy: Identifies complex adulterants.
5. DNA barcoding confirms geographic claims and identifies the provenance of flowers.
6. Electrical Conductivity and Moisture Tests: Quick first screening for purity[14-16].

Case Studies and Research Findings:

1. India (FSSAI, 2020): Adulteration with Rice Syrup[17]

A thorough examination into the quality of honey supplied in Indian marketplaces was carried out in 2020 by the Food Safety and Standards Authority of India (FSSAI). NMR spectroscopy and isotope ratio mass spectrometry (IRMS) were used to examine samples from well-known brands. The findings showed that high-fructose corn syrup (HFCS) and rice syrup (C3 sugars) were the main sources of adulteration in 77% of commercial honey samples. The adulteration was sufficiently complex to evade simple purity testing. Significant worries regarding the risks to public health were brought up by the study, particularly the hepatic and metabolic damage linked to prolonged use of these tainted products. In the wake of the disclosure, the Food Safety and Standards Authority of India (FSSAI) enforced more stringent adherence to the Food Product Standards and Food Additives Regulations, 2011 and heightened oversight of honey imports from China and Malaysia.

2. China (2019): Large-Scale Honey Dilution Using Corn Syrup[18]

In 2019, there were numerous accusations of widespread honey adulteration in China, one of the top producers of honey worldwide. In order to boost yield and replicate the viscosity and sweetness of pure honey, natural honey was extensively diluted with corn syrup and rice syrup, according to analytical testing utilising carbon isotope ratio analysis and HPLC. Up to 40–50% of certain honey batches were adulterated. Elevated HMF levels in the tainted samples also suggested overheating during processing. The European Union temporarily banned a number of Chinese honey imports as a result of this practice, which also damaged export confidence. Health professionals cautioned that using these items may increase the risk of obesity, non-alcoholic fatty liver disease (NAFLD), and insulin resistance.

3. United States: Synthetic Honey Imports (FDA, 2018)[19]

When the U.S. Food and Drug Administration (FDA) discovered a significant honey import scam in 2018, it discovered that substantial shipments of honey from Southeast Asia—primarily China and Vietnam—that were labelled as "pure honey" actually contained artificial colouring agents,

industrial sugars, and sweeteners. GC-MS and isotope ratio measurements were used to identify the bogus items. The FDA launched criminal investigations and confiscated more than 500 tonnes of counterfeit honey. Chloramphenicol, a prohibited antibiotic that poses serious dangers such aplastic anaemia and antibiotic resistance, was detected in toxicological investigations. The case reinforced customs testing for imported honey and brought attention to the pressing need for worldwide traceability mechanisms.

4. European Union (2021): Pervasive Import Honey Adulteration[20]

In 2021, the Joint Research Centre of the European Commission carried out a thorough analysis of honey imports from 20 nations in accordance with the EU Honey Directive (2001/110/EC). With significant concentrations of added sugars and C4 plant syrups, 46% of the 320 samples that were examined did not meet purity standards. Derivatives of maize and beetroot sugar were the main adulterants. Patterns of adulteration were validated by isotope analysis and advanced NMR profiling. Concerns regarding consumer deception and labelling fraud were brought up by the study. After that, the European Parliament suggested requiring origin traceability and imposing sanctions on imported honey that has been tampered with. Chronic exposure to these adulterants can increase glycaemic load, which raises the prevalence of diabetes and obesity in Europe.

5. Identifying C4 Sugars in Supermarket Brands in Australia (2019)[21]

In 2019, researchers at the University of Melbourne used C4 sugar isotope ratio assays to evaluate 100 commercial honey brands. Significant amounts of C4 sugars, mostly high-fructose corn syrup, which are not normally present in honey made from flower nectar, were found in 27% of honey samples. The majority of the tampered samples were from cheap supermarket brands. Increased caloric density and a higher risk of metabolic and cardiovascular disorders were among the toxicological ramifications. In order to protect local beekeepers and customers, the Australian Competition and Consumer Commission (ACCC) intervened and strengthened the enforcement of food labelling regulations as a result of the study.

6. Antibiotic Residues in Pakistan (2020)[22]

In 2020, 60 samples of local honey were examined for antibiotic contamination by the Pakistan Council of Scientific and Industrial Research (PCSIR). According to LC-MS/MS analysis, over 50% of them had residues of the antibiotics streptomycin, chloramphenicol, and oxytetracycline, which are used to treat bee illnesses. These antibiotics pose a risk to human health since they can result in antibiotic resistance, alteration of the gut microbiota, and hypersensitivity reactions. The primary culprits, according to the researchers, were the overuse of veterinary medications and the absence of regulation in apiculture techniques. Calls for the adoption of Good Beekeeping Practices (GBPs) and routine residue testing prior to market release resulted from the findings.

7. Saudi Arabia (2021): Overheating Causes Excessive HMF Formation[23]

The Saudi Food and Drug Authority (SFDA) found HMF values above 100 mg/kg in 2021 when they examined honey samples from local shops. This is significantly higher than the Codex Alimentarius standard of 40 mg/kg. The extended heating that occurred during the manufacturing and storage of the honey was blamed for the elevated HMF levels. Because of its recognised

cytotoxic and mutagenic properties, HMF may cause liver damage. For honey quality certification, the SFDA advised regular HMF testing and temperature-controlled processing. The results emphasised how inappropriate heating and storage affect the safety of honey.

8. Egypt (2018): Glucose and Fructose Syrup Detection[24]

50 honey samples from domestic and foreign sources were examined in an analytical investigation conducted in 2018 by the National Research Centre in Cairo. Researchers discovered that 60% were tampered with using artificial glucose and fructose syrups using FTIR spectroscopy and HPLC. Reduced antioxidant activity, decreased pollen count, and changed viscosity were all characteristics of the tainted honey. According to health evaluations, frequent use may cause oxidative damage and hyperglycemia. In order to prevent adulteration in the country's honey markets, the Egyptian government later implemented purity standards based on Codex.

9. Brazil (2022): Honey Containing Pesticide Residues[25]

The Brazilian Food Safety Authority (ANVISA) conducted a statewide assessment in 2022 and found that about 30% of honey samples taken from agricultural and rural areas had pesticide residues. Neonicotinoids, glyphosate, and organophosphates were among the substances found. Because of tainted floral sources, these compounds may remain in honey. Neurotoxic, hepatotoxic, and endocrine-disruptive consequences are possible with prolonged exposure. In order to reduce pollution, the research recommended buffer zones to be established around beekeeping regions and more stringent regulations on agricultural pesticides. The case illustrated the intricate relationship between honey safety and agricultural pollution.

10. Nigeria (2020): Spectroscopic Identification of Adulterated Cane Sugar[26]

In 2020, 80 honey samples from Nigerian markets were examined by researchers at the University of Lagos using Fourier-transform infrared spectroscopy (FTIR). According to the results, 65% of them were tampered with using invert syrup or cane sugar. Spectral analysis revealed distinct carbohydrate peaks that matched the addition of sucrose. Low enzymatic activity and decreased nutritional content were the outcomes of the adulteration. After consistent use, consumers reported increased blood sugar and gastrointestinal distress. The study advocated national regulation for honey authenticity utilising IR-based testing and indicated that the main economic motivation for adulteration was economic.

Regulatory and Safety Standards:

- Adulteration of honey has become a significant issue for fair trade and public health. To guarantee the safety, authenticity, and purity of honey, regulatory bodies worldwide have set particular norms and rules.

- The Food Safety and Standards (Food Products Standards and Food Additives) Regulations, 2011 establish criteria like the fructose-to-glucose ratio, sucrose content (<5%), moisture content (<20%), ash content (<0.6%), electrical conductivity, and Hydroxymethylfurfural (HMF) levels (<80 mg/kg) that are used by the Food Safety and Standards Authority of India (FSSAI) to regulate honey quality in India.

- In order to identify sugar syrup adulteration, the FSSAI has also required the use of NMR fingerprinting and isotope ratio studies.

- The worldwide standard for honey is provided by Codex Alimentarius (Codex Standard 121981, Rev. 2001), which lays forth requirements for pollutants, composition, and labelling. Further enforcing quality standards for both local and imported honey is the European Union Honey Directive (2001/110/EC), which mandates zero tolerance for antibiotics, colorants, and added sugars[27].

- The Standards of Identity for Honey, which emphasize correct labelling and forbid adulteration under the Food, Drug, and Cosmetic Act (FDCA), have been put into effect by the U.S. Food and Drug Administration (FDA) and the U.S.

- Department of Agriculture (USDA). Similarly, honey quality is regulated by the China National Food Safety Standard GB 14963-2011, which establishes limits for reducing sugars, heavy metals, and antibiotics[28].

Public Health and Economic Implications:

- There are economical and toxicological issues with honey adulteration. The use of chemical preservatives or industrial sugar syrups (such as high-fructose corn syrup or rice syrup) can have a number of negative health impacts.

- Long-term use of these adulterants raises the risk of metabolic diseases such non-alcoholic fatty liver disease, diabetes, and obesity. Overheating or prolonged storage can produce high quantities of hydroxymethylfurfural, which can be cytotoxic and mutagenic, especially to young children[29].

- Antimicrobial resistance and possible carcinogenicity have been linked to the presence of pesticides and antibiotic residues (such as tetracycline's and chloramphenicol) in some tampered honey samples.

- Economically, adulterating honey damages consumer confidence and costs legitimate beekeepers a lot of money. Low-cost, artificial replacements unfairly compete with genuine honey producers, reducing their revenue and creating market volatility[30].

- Global trade estimates indicate that the real honey sector loses billions of dollars every year as a result of counterfeit shipments and brand harm caused by contaminated honey. Furthermore, when adulteration scandals occur, nations that rely on honey exports, such as China, Brazil, and India, face import restrictions and trade prohibitions, damaging their reputations.

- Due to commercial pressures that also hinder healthy beekeeping techniques that are vital for crop pollination and ecological balance, honey adulteration is a multifaceted dilemma that affects commerce, biodiversity, and health in addition to being a food fraud concern[31].

Future Perspectives:

- Innovative technological, governmental, and educational measures are needed to combat honey adulteration.

- For precise identification of adulterants at trace levels, future trends call for the use of cuttingedge analytical techniques including DNA barcoding, Fourier Transform Infrared (FTIR), Isotope Ratio Mass Spectrometry (IRMS), and Nuclear Magnetic Resonance (NMR) spectroscopy[32].

- Pattern recognition of genuine honey profiles based on botanical and geographic origin may be further improved by combining machine learning and chemometric models.

- Supply chain manipulation may be avoided with the use of emerging technologies like Blockchain-based traceability systems, which might guarantee transparent tracing from hive to customer. Using smart packaging and authenticity verification via QR codes can enable customers to instantly check the purity of products[33].

- To prevent cross-border adulteration, the FDA, EFSA (European Food Safety Authority), FSSAI, and other organizations must harmonies worldwide honey standards and establish international data-sharing networks.

- Investigating natural indicators of authenticity (such as distinct phenolic chemicals, pollen DNA, and enzymatic activity) can help researchers identify authentic honey types. A significant part will also be played by expanding public awareness campaigns on how to recognize pure honey, comprehend labelling, and support ethical products[34].

- The future of honey purity depends on a cooperative strategy that combines rigorous regulation, scientific advancement, and customer involvement. Global markets can only guarantee the sustainability, safety, and authenticity of this priceless natural commodity by means of these concerted efforts[35].

CONCLUSION:

A significant global food safety and economic problem is honey adulteration. Once valued for its medicinal purity, honey is now commonly tainted by heat treatment, chemical additions, and dilution with sugar syrups. Stopping this malpractice requires a concerted effort from consumers, beekeepers, analytical labs, and regulatory agencies. Transparent labelling, regular surveillance, and stricter adherence to EU, FSSAI, and Codex Alimentarius requirements will all improve product authenticity. Rapid field detection can be facilitated by technological interventions like as portable purity analyzers and Blockchain traceability. Additionally, the market for fake goods can be decreased by educating consumers on how to spot real honey and how to support recognized producers. Stopping this malpractice requires a concerted effort from consumers, beekeepers, analytical labs, and regulatory agencies. Transparent labelling, regular surveillance, and stricter adherence to EU, FSSAI, and Codex Alimentarius requirements will all improve product authenticity. Rapid field detection can be facilitated by technological interventions like as portable purity analyzers and Blockchain traceability. Additionally, the market for fake goods can be decreased by educating consumers on how to spot real honey and how to support recognized producers. In the end, preserving honey's authenticity is crucial for public health as well as for business. Maintaining honey's purity protects its cultural, therapeutic, and nutritional value for next generations.

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