

Detection and Control of Adulterants in Milk

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Abstract

Milk is one of the most essential and widely consumed staple foods, valued for its rich nutritional composition, including proteins, fats, vitamins, and minerals necessary for human growth and health. However, the increasing demand for milk, coupled with economic incentives, has led to the widespread issue of milk adulteration, posing serious concerns for food safety and public health. Adulteration involves the addition of harmful or inferior substances to milk, either to increase volume or to enhance its apparent quality. Milk adulterants can be broadly categorized as intentional and unintentional. Intentional adulterants include water, urea, detergents, starch, and synthetic chemicals, which are added to maximize profit. Unintentional adulterants, such as antibiotic residues, pesticides, heavy metals, and aflatoxins, may enter milk through contaminated feed, water, or environmental exposure. These adulterants can have severe health implications, ranging from gastrointestinal disturbances to long-term toxic effects, including organ damage and carcinogenic risks. Various detection methods have been developed to identify adulterants in milk. Traditional methods, such as lactometer tests, iodine tests, and organoleptic evaluation, provide simple and cost-effective means for preliminary screening. In contrast, advanced analytical techniques, including chromatography, spectroscopy, and biosensor-based approaches, offer higher sensitivity, specificity, and accuracy in detecting even trace levels of contaminants. To address this issue, effective control strategies are essential, including the implementation of strict quality control measures, adherence to food safety regulations, and the adoption of Hazard Analysis and Critical Control Point (HACCP) systems. Additionally, increasing consumer awareness and the development of rapid, low-cost detection technologies are crucial for ensuring milk safety. Overall, tackling milk adulteration requires a combined effort from regulatory authorities, industry stakeholders, and consumers to safeguard public health and maintain food quality standards.

Keywords: Chemical contaminants, dairy industry, detection techniques, food safety, milk adulteration, quality control

INTRODUCTION

Milk is one of the most important and widely consumed foods in the human diet, recognized for its high nutritional value and essential role in maintaining health. It serves as a rich source of high-quality proteins, essential amino acids, fats, lactose, vitamins (such as A, D, and B-complex), and minerals, particularly calcium and phosphorus. Due to its balanced composition, milk is considered a complete food, especially beneficial for infants, children, pregnant women, and the elderly. Regular consumption of milk and dairy products supports bone development, muscle growth, and overall metabolic functions [1].

Despite its nutritional importance, milk is highly susceptible to adulteration, which has become a major concern in the dairy industry.

The primary reasons for milk adulteration are economically in nature. Increasing demand for

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milk, coupled with limited supply, creates pressure on producers and distributors to maximize profits. Adulterants, such as water, are commonly added to increase volume, while substances like starch, urea, and detergents are used to mimic the original composition and appearance of pure milk. In addition, lack of strict monitoring, inadequate infrastructure, and weak enforcement of food safety regulations further encourage such unethical practices [2].

Milk adulteration is a significant public health issue, as the consumption of contaminated milk can lead to both acute and chronic health problems. Short-term effects include gastrointestinal disturbances, such as nausea, vomiting, and diarrhea, while long-term exposure to toxic substances like heavy metals and chemical adulterants can result in organ damage, neurological disorders, and even cancer. Children, pregnant women, and immunocompromised individuals are particularly vulnerable to these adverse effects [3].

TYPES OF MILK ADULTERANTS

Milk adulterants can be broadly classified into intentional and unintentional categories, depending on whether they are deliberately added or accidentally introduced during production, handling, or storage.

Intentional Adulterants

Intentional adulterants are deliberately added to milk to increase volume, improve appearance, or enhance shelf life, often for economic gain.

- *Water*: Water is the most frequently used adulterant, added to increase the volume of milk. However, this reduces the nutritional value and may introduce microbial contamination if the water is impure.
- *Urea*: Urea is added to increase the nitrogen content, thereby falsely elevating the protein level in milk. Excess intake can lead to kidney dysfunction and metabolic disturbances [4].
- *Detergents*: Detergents are used to emulsify fats and create a foamy appearance like natural milk. Their presence can cause gastrointestinal irritation and toxicity.
- *Starch*: Starch is added to increase the thickness and viscosity of diluted milk. While not highly toxic, it can affect digestion and is especially harmful to diabetic individuals.
- *Formalin*: Formalin is added as a preservative to extend the shelf life of milk by preventing microbial growth. It is highly toxic and has carcinogenic potential.
- *Synthetic Milk Components*: Synthetic milk is prepared by mixing substances, such as urea, detergents, vegetable oils, and salts, to imitate natural milk. This type of adulteration poses severe health risks due to the presence of harmful chemicals [5].

Unintentional Adulterants

Unintentional adulterants enter milk through environmental exposure, contaminated feed, or improper veterinary practices.

- *Antibiotic Residues*: These residues result from the use of antibiotics in dairy animals for disease treatment. Consumption of such milk can lead to antibiotic resistance and allergic reactions.
- *Pesticides*: Pesticides may enter milk through contaminated fodder and water. Chronic exposure can have toxic effects, including endocrine disruption and neurological disorders.
- *Aflatoxins*: Aflatoxins are toxic compounds produced by certain fungi present in contaminated animal feed. Aflatoxin M1, found in milk, is particularly harmful and has carcinogenic properties [5, 6]. Common adulterants and their sources are given in Table 1.

HEALTH HAZARDS OF MILK ADULTERATION

Milk adulteration poses serious risks to human health, as the addition of harmful substances compromises both the safety and nutritional quality of milk. The health effects of adulterated milk can be categorized into short-term and long-term impacts, with certain groups being more vulnerable [7].

Table 1. Common Milk Adulterants, Sources and Health Effects.

Adulterant	Type	Source/Reason for Addition	Health Effects
Water	Intentional	Added to increase volume and profit	Reduced nutrition, risk of water-borne diseases
Urea	Intentional	Increases nitrogen content to mimic protein	Kidney damage, metabolic disorders
Detergents	Intentional	Improves foaming and appearance	Gastrointestinal irritation, toxicity
Starch	Intentional	Enhances thickness of diluted milk	Digestive issues, harmful for diabetics
Formalin	Intentional	Acts as preservative to extend shelf life	Toxic, carcinogenic, organ damage
Synthetic milk	Intentional	Prepared using chemicals to imitate milk	Severe toxicity, long-term health risks
Antibiotic residues	Unintentional	Use of drugs in dairy animals	Antibiotic resistance, allergic reactions
Pesticides	Unintentional	Contaminated feed and water	Neurotoxicity, hormonal imbalance
Heavy metals (Pb, As, Hg)	Unintentional	Environmental pollution	Organ damage, neurological disorders
Aflatoxins (M1)	Unintentional	Fungal contamination in feed	Carcinogenic, liver damage

Short-Term Effects

Consumption of adulterated milk can lead to immediate health problems, particularly affecting the gastrointestinal system. Common symptoms include diarrhea, nausea, vomiting, abdominal pain, and bloating. These effects are often caused by contaminants, such as detergents, urea, and contaminated water, which irritate the digestive tract. In some cases, toxic adulterants like formalin can lead to acute poisoning, resulting in severe health complications, such as dizziness, respiratory distress, and even organ failure if consumed in high amounts. Additionally, microbial contamination due to poor-quality water can increase the risk of infections [8].

Long-Term Effects

Chronic exposure to adulterated milk can have more severe and lasting health consequences. Continuous intake of toxic substances, such as heavy metals (lead, arsenic, and mercury) can result in their accumulation in the body, leading to organ damage, particularly affecting the liver, kidneys, and nervous system. Aflatoxins present in contaminated milk are known carcinogens and have been associated with an increased risk of liver cancer. Similarly, prolonged consumption of milk containing pesticide residues can disrupt hormonal balance and cause neurological disorders. The presence of antibiotic residues in milk may contribute to the development of antibiotic resistance, reducing the effectiveness of essential medications [9].

IMPACT ON CHILDREN AND VULNERABLE POPULATIONS

Children, pregnant women, the elderly, and immunocompromised individuals are particularly susceptible to the harmful effects of milk adulteration. In children, adulterated milk can impair growth, weaken immunity, and cause developmental issues due to inadequate nutrient intake and exposure to toxins. Pregnant women may experience adverse effects that can impact fetal development, while elderly individuals with weakened physiological systems are more prone to toxicity and infections. These vulnerable groups are at a higher risk even at lower levels of contamination, making milk safety a critical public health priority [10].

DETECTION METHODS OF MILK ADULTERANTS

The detection of adulterants in milk is essential to ensure its quality, safety, and suitability for consumption. Various methods ranging from simple traditional techniques to advanced analytical tools have been developed for this purpose [11].

Traditional Methods

Traditional methods are simple, cost-effective, and suitable for preliminary detection, especially at the household or field level.

- *Lactometer Test (for Water Adulteration)*: A lactometer measures the density of milk. Dilution with water lowers the density, indicating possible adulteration.
- *Iodine Test (for Starch)*: Addition of a few drops of iodine solution to milk produces a blue or black color if starch is present.
- *Foam Test (for Detergents)*: Shaking milk vigorously results in persistent foam in the presence of detergents.
- *Organoleptic Methods*: Sensory evaluation based on taste, smell, and appearance can provide initial clues. For example, soapy taste or unusual odor may indicate adulteration [12].

Advanced Analytical Techniques

Advanced methods provide higher accuracy, sensitivity, and reliability in detecting even trace levels of adulterants.

- *Chromatography (HPLC, GC)*: High-performance liquid chromatography (HPLC) and gas chromatography (GC) are used to identify and quantify chemical contaminants such as pesticides, antibiotics, and toxins.
- *Spectroscopy (FTIR, NIR)*: Fourier transform infrared (FTIR) and near-infrared (NIR) spectroscopy allow rapid and non-destructive analysis of milk composition, helping detect adulterants based on spectral patterns.
- *Biosensors*: Biosensor-based techniques use biological elements (enzymes, antibodies) to detect specific adulterants with high sensitivity and rapid response.
- *PCR-Based Methods*: Polymerase chain reaction (PCR) is used to detect microbial contamination and genetic material, especially useful in identifying adulteration in processed dairy products [13, 14].

Rapid Detection Kits

Rapid detection methods are gaining popularity due to their ease of use, portability, and quick results.

- *Field-Level Testing Kits*: These kits are designed for on-site detection of common adulterants, such as urea, starch, and detergents, providing immediate results.
- *Paper Strip Tests*: Simple strips that change color upon contact with adulterated milk, offering a quick and inexpensive detection method.
- *Mobile-Based Detection Technologies*: Emerging technologies integrate smartphone-based sensors and applications for real-time analysis and monitoring of milk quality [15].

CONTROL AND PREVENTION STRATEGIES

Effective control and prevention of milk adulteration require a comprehensive approach involving all stages of the dairy supply chain, from production to consumption. The implementation of strict quality measures, regulatory frameworks, and consumer awareness programs is essential to ensure milk safety.

At Farm Level

- *Hygienic Milking Practices*: Maintaining cleanliness during milking is crucial to prevent contamination. Proper sanitation of equipment, clean water supply, and healthy handling practices help ensure the quality of raw milk.
- *Animal Health Management*: Regular veterinary care, proper feeding, and controlled use of antibiotics are important to avoid the presence of harmful residues in milk. Observing withdrawal periods after medication is essential [4].

Processing Level

- *Quality Testing and Standardization*: Milk should undergo rigorous quality checks at collection and processing centers to detect adulteration at an early stage. Standardization ensures consistency in composition and quality.

- *Implementation of HACCP*: The Hazard Analysis and Critical Control Point (HACCP) system helps identify potential hazards and establish control points throughout processing, ensuring food safety [7].

Regulatory Measures

- *Food Safety Laws and Standards*: Strict enforcement of food safety regulations, such as those set by national and international authorities, is essential. In India, organizations like the Food Safety and Standards Authority of India (FSSAI) play a key role in setting standards and monitoring compliance.
- *Regular Inspections and Penalties*: Routine monitoring, sampling, and testing by regulatory agencies, along with strict penalties for violations, help deter adulteration practices [13].

Consumer Awareness

- *Awareness Programs*: Educating consumers about the risks of adulterated milk and methods to identify it can empower them to make safer choices.
- *Household Detection Methods*: Simple tests that can be performed at home, e.g., iodine test for starch, checking consistency) can help consumers detect basic adulteration [4].

CHALLENGES IN DETECTION AND CONTROL

Despite advancements in detection techniques and regulatory frameworks, several challenges continue to hinder the effective control of milk adulteration.

Technical Challenges

- *Maintaining Accuracy and Sensitivity*: Detecting adulterants at very low concentration requires highly sensitive instruments, which may not always be available.
- *Complex Nature of Adulterants*: Modern adulteration practices involve sophisticated chemicals that are difficult to detect using conventional methods [6].

Economic Challenges

- *High Cost of Advanced Techniques*: Technologies, such as chromatography and spectroscopy, are expensive and require skilled personnel, limiting their use in rural and small-scale settings.
- *Infrastructure Limitations*: Lack of proper laboratory facilities and testing equipment in developing regions restricts effective monitoring [8].

Consumer Challenges

- *Lack of Awareness*: Many consumers are unaware of common adulterants and their health risks, leading to continued exposure.
- *Dependence on Unorganized Sector*: In many regions, people rely on local milk vendors where quality control is minimal.

Regulatory Challenges

- *Weak Implementation of Laws*: Although regulations exist, inconsistent enforcement reduces their effectiveness.
- *Inadequate Monitoring Systems*: Limited manpower and resources affect regular inspection and surveillance [7].

CONCLUSION

Milk adulteration remains a serious issue affecting food safety, public health, and consumer trust. The presence of both intentional and unintentional adulterants compromises the nutritional quality of milk and poses significant health risks, ranging from mild gastrointestinal disturbances to severe long-term diseases. Various detection methods, including traditional techniques and advanced analytical tools, have been developed to identify adulterants; however, challenges related to cost, accessibility,

and implementation persist. Effective control strategies, including good farming practices, strict regulatory measures, and consumer awareness, are essential to address this issue. Ensuring the safety and quality of milk requires a collaborative effort from all stakeholders, including farmers, industry professionals, regulatory authorities, and consumers. With continued advancements in technology and increased awareness.

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