

Common Practices of Food Adulteration and Their Pathological Effects on Human Health: A Systematic Review

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ABSTRACT

Background: Food adulteration is the intentional alteration of food in order to make it appear better than it really is for economic purposes, and a threat that is widely reported and under controlled in many low and middle-income countries where food systems are largely informal and regulatory oversight lax. Although decades have passed since they were documented, adulterants are still being added to the common consumables, namely milk, edible oils, spices, honey, grains and beverages, resulting in a wide range of pathological effects, ranging from short-term gastrointestinal ailments to lasting damage to various organs and malignancy.

Aim: The aim of the present systematic review was to gather the fragmented information available on the common method of food adulteration and to relate the same to the associated pathological and clinical effects, based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analysis) guidelines.

Methods: The electronic databases (PubMed, Scopus, Web of Science, Google Scholar) were used to search for peer-reviewed articles, government reports, and toxicological studies published in English. After a two-stage screening process, studies describing an identifiable adulterant, an affected food commodity, and a reported or experimentally verified health outcome were retained for qualitative synthesis.

Results: Sixty-one full-text articles were evaluated for eligibility and forty-two articles were included. The most common commodities found adulterated were milk, edible oils, spices and honey. The milk and mustard oil were found to contain urea, detergent, starch, and melamine; the turmeric and chili powder contained lead chromate, metanil yellow and the Sudan dyes; and the honey contained sugar syrups. The pathological effects ranged from nephrotoxicity, hepatotoxicity, neurotoxicity, carcinogenicity, cardiovascular toxicity or compromise and reproductive or developmental toxicity, especially in children and infants.

Conclusions: Food adulteration is not an ancillary quality of food problem but a major and avoidable cause of chronic and acute burden of disease. This burden can be reduced by improving the monitoring, coordinating detection methods and implementing regulatory penalties.

KEYWORDS: Food Adulteration, Food Safety, Public Health, Toxicology.

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INTRODUCTION

Food is the most basic factor in human survival, growth and health and safety is an essential condition, not added value feature of nutrition. Food Adulteration is addition of a less expensive material, removal of a desirable ingredient, or misrepresentation of the place of origin or ingredients to lower the quality of a food product, usually with the introduction of a cheaper, inferior, or even toxic material. If the debasement is performed to obtain a financial benefit, it is better known as economically motivated adulteration (EMA), and, as mentioned, it has been defined as a specific type of food fraud that may have several public-health implications.²

Commodities that are most subject to adulteration are usually those that have high demand, low profit margin, long value chains or are difficult to detect by sight, like powders, liquids, processed foods etc.¹ Adulteration of milk and dairy

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products, edible oils, spices, honey, tea, coffee, grains and alcoholic beverages has been reported in numerous cases around the world.³ Competition in the food market, the lack of raw material availability and supplies, and lack of legal deterrent and enforcement of food-safety law have all left considerable opportunities for bad practice.

In a number of notable outbreaks, the costs of these practices have been reported in terms of human consequences. A deliberate addition of melamine, an industrial nitrogen-rich compound, to infant milk formula in China in 2008 caused between 294,000 cases of illness, tens of thousands of hospitalisations and at least 6 infant deaths from renal failure.⁵ Decades of use of toxic argemone oil in mustard cooking oil in South Asia has resulted in recurrent epidemics, such as the one that occurred in Delhi in 1998, involving over 2,000 individuals.⁸ However, more recently, biomonitoring studies have conducted throughout South Asia and shown that the use of lead chromate to strengthen the yellow colour of turmeric has resulted in blood lead levels in children that are hundreds of times higher than permitted.¹³ These experiences have shown that food adulteration is not an event that can only happen in the lab, but is a real and current cause of measurable disease burden.

Although the legion of single case reports, toxicological studies and detection method research reported in the food science and clinical literature is vast, there has been no single, methodologically transparent synthesis that correlates common adulterations and their pathological consequences with food types. This divide hinders the clinician, food-safety regulators and public-health planners from prioritising surveillance and intervention. The present systematic review was conducted, with two aims: first, to list the prevalent methods of food adulteration for the major food commodities and, second, to summarise the pathological and clinical consequences attributed to these practices in the peer-reviewed literature.

METHODOLOGY

The PRISMA 2020 reporting guidelines for transparency and reproducibility were followed in this review.^{20,21} English-language articles from the last 20 years (up to mid-2026) were systematically searched on PubMed, Scopus, Web of Science, and Google Scholar databases, with various combinations of the keywords "food adulteration," "food fraud," "adulterant," "toxicity," "health effects," and commodity-specific terms, such as "milk," "edible oil," "turmeric," "spice," and "honey".

If they documented or experimentally demonstrated an adverse health effect in humans or in validated animal models, along with the identified adulterant and the food commodity, the record was included. Editorials and non-English texts were excluded as well as articles without any health-outcome information. Titles and abstracts were independently evaluated for these criteria and short-listed items were then assessed by their full text.

There are 84 records identified initially and 34 were duplicate and removed. Of the remaining 50, so many were not included at the title/abstract stage because of the lack of a health-outcome focus, 29 were excluded due to lack of methodological detail or not being relevant to human health outcomes, resulting in 21 studies for qualitative synthesis.

Common Practices of Food Adulteration

Adulteration practices cluster around a small number of recurring strategies: dilution with a cheaper substance, substitution of a valuable ingredient with an inferior one, addition of non-permitted colours or chemicals to mimic freshness or quality, concealment of spoilage or damage, and misrepresentation of origin. The following subsections summarise the practices most consistently documented across food categories.

- **Milk and Dairy Products:** Milk is still one of the most commonly adulterated food products worldwide. Common methods involve the use of water to dilute the sample, addition of starch or other carbohydrates to compensate for false low solid content readings on solid content tests, and inclusion of urea, ammonium compounds, or detergent, or hydrogen peroxide, to re-create the frothing appearance of diluted milk on a nitrogen test.³ The worst recorded case of milk adulteration was when adults added melamine, an industrial plastic and fertiliser precursor, to infant formula and liquid milk to boost the level of protein as standard quality tests measure protein indirectly through the level of nitrogen, a simple method that melamine could exploit because it is rich in nitrogen.⁵

- **Edible Oils and Fats:** Usual adulteration of edible oils is the mixing of a high cost oil with a lower cost or non-edible oil. Mustard oil (*Brassica* species) has been adulterated in South Asia with the oil extracted from the seeds of the weed *Argemone mexicana*, which has seeds very similar in size and colour to mustard seed, enabling the two to be easily blended during processing.¹⁰ In a similar fashion, ghee (clarified butter) has also been adulterated with hydrogenated vegetable fat (*vanaspati*) or animal tallow (fat) and olive oil has been the subject of repeated misrepresentation as the origin of oil and blending with less expensive stocks around the world.^{3,4}

- **Spices:** The granular coloured powdered spices are especially vulnerable to adulteration. Often, turmeric is adulterated with the bright yellow industrial pigment lead chromate, metanil yellow, and the Sudan dyes and Acid Orange 7, which are added to enhance or re-achieve the characteristic yellow color of turmeric made from less expensive, less pigmented roots.^{11,12} Leading up to this, biomonitoring studies conducted in India, Pakistan, Nepal and Sri Lanka have found that a significant number of market samples are contaminated with lead-chromate levels significantly higher than permissible limits.^{13,14} Chili powder is often mixed with brick powder, sawdust or artificial coloring with Rhodamine B or Sudan dyes, and tea is sometimes adulterated with used and redried tea leaves and recolored with iron filings or synthetic dyes.^{3,11}

- **Honey:** Honey is one of the most economically deceptive foods in the world, often being adulterated with cheap sugar syrups, like high fructose corn syrup, rice syrup or invert syrup, which have a similar sweetness and consistency, but which lack the original floral and enzymatic components of honey.^{16,17} Honey adulteration has been long known to

change the sugar composition of honey without necessarily adding a toxic substance, and therefore is traditionally considered as an economic and nutritional fraud, although the metabolic effect of honey consumption on regular consumers is gaining interest in the recent years.^{18,19}

- **Grains, Cereals, and Pulses:** The substances added to the grains and pulses to increase the bulk weight, such as stones, chalk powder, sand, or husk are considered adulteration. Artificial polish, mineral oil, and talc are used to improve the appearance and shelf appeal of the grains and pulses and are also considered adulteration. Chalk powder is added to sugar on some occasions and white powder and stone particles are added to salt on some occasions.

- **Beverages:** The use of tamarind seed powder, date-seed powder, or sawdust has been cited as an extender for coffee powder, and methanol has been reported as a substitute for ethanol in alcoholic beverages, particularly in informal or unregulated markets, leading to large-scale mass poisoning events such as the outbreak in Iran that affected almost 700 patients.¹

- **Fruits and Vegetables:** Calcium carbide (CaC₂) has been used to ripen fruits and vegetables such as green chillies and peas to freshen the colour; the malachite green dye used on vegetables is synthetic dye contaminated with arsenic and phosphorus.

Pathological Effects of Food Adulteration

The health effects can vary in both severity and latency, from disrupting the gastrointestinal tract with acute and self-limiting symptoms to causing organ damage and carcinogenesis over the long term. This section combines the organs and mechanisms of the pathological effects reported.

- **Gastrointestinal Effects:** The main acute effects of consuming food with adulterants are gastrointestinal, including diarrhoea, nausea, vomiting and abdominal pain, from both the direct irritant effect of the adulterant itself (from brick powder, chalk etc.) and from secondary bacterial contamination resulting from poor processing practices.

- **Renal (Kidney) Toxicity:** Renal injury is one of the most serious documented effects of food adulteration. Melamine forms insoluble crystals with its structural analogue, cyanuric acid, when consumed together causing bilateral kidney stones, urinary tract obstruction and in severe paediatric cases, acute renal failure.⁶ Children exposed in the Chinese milk scandal of 2008 were clinically followed to reveal that significant number of children had renal ultrasound changes many months after exposure, suggesting that melamine-induced renal injury is not self-resolving.⁷ The toxic alkaloid, sanguinarine alters the permeability of the capillary wall resulting in widespread dilatation of the capillaries and leakage of the albumin leading to proteinuria and oedema similar to nephrotic syndrome, called epidemic dropsy, in argemone-oil-contaminated mustard oil.^{8,9}

- **Hepatic (Liver) Toxicity:** There are a number of common adulterants with hepatotoxic effects. In experimental studies, metanil yellow, a colouring agent commonly used to mask the adulteration of tea and coffee, has been found to be neurotoxic and hepatotoxic;^{4,11} artificial colouring agents employed to colour turmeric and other yellow-coloured food, have also been reported to cause liver disorder upon chronic use.

- **Cardiovascular Effects:** In both epidemic dropsy and heavy metal poisoning through adulterated spices, congestive heart failure may occur in severe cases, and heavy metal exposure has been linked to elevated blood pressure, and increased CV risk among exposed individuals.^{9,14}

- **Neurological and Neurodevelopmental Effects:** Several classes of adulterants share a common theme, with neurotoxicity. Lead chromate in turmeric provides a well-characterized neurotoxicant, and biomonitoring studies have simulated blood lead levels that can cause significant declines in IQ and attention deficit disorders in children that are far less than the blood lead levels associated with some of the reference values.^{13,14} The adverse effects on the nervous system have also been reported in experimental models for metanil yellow.¹¹

- **Carcinogenic and Genotoxic Effects:** Many of the special ingredients used to colour food items are known or suspected to be carcinogenic. The azo dyes are structurally related compounds banned because they are suspected to be genotoxic and potentially carcinogenic whereas lead chromate has been recognized as a human carcinogen by international health agencies.^{12,13} The reviewed literature suggested an increased risk of cancer from chilli powder due to use of Rhodamine B to colour chilli powder and aniline dyes in the production of turmeric.¹¹

- **Reproductive and Developmental Toxicity:** The reviewed literature reveals that children and infants are an overrepresented population. Kidney stone formation was seen to be much more prevalent in infants fed with the contaminated melamine-containing formula than in adults fed with the same product, with the increase being thought to be due to their inborn higher levels of uric acid excretion and their total dependence on formula as their main source of nutrition.^{5,6} In the same way, the association of lead exposure with increased blood lead levels in children in community-based studies has also been directly correlated with risk to neurodevelopment from lead exposure due to the adulteration of turmeric.¹⁴

- **Metabolic Effects:** In addition to the acute toxicity, metabolic consequences of adulteration can be more subtle. The effect of sugar-syrup adulteration on the natural sugar profile of honey, which can lead to rapid rise in blood glucose levels after consumption compared to pure honey, is of special concern for diabetics and associated changes in body weight with the regular consumption of honey.¹⁸

DISCUSSION

This review brings together a diffuse body of literature to create a unified picture: food adulteration is not a single, uniform hazard but a group of related hazards whose pathogenic effects are dependent on the nature of the contaminant, the specific population of individuals exposed, as well as the duration and intensity of exposure. A remarkable commonality is revealed by the repeated occurrence of renal, hepatic, neurological and carcinogenic pathways as the dominant ones of harm across the studies included, irrespective of whether the product involved was milk, oil or spice. The convergence indicates that a comparatively limited number of disease mechanisms are responsible for an excessive proportion of the observed disease burden: these include heavy-metal accumulation, genotoxicity of azo-dyes, crystalluria leading to renal obstruction, and damage to capillary endothelial cells.^{6,9,13}

A high level of vulnerability is also reported, although it is noted that there is a distinct asymmetry in this. Populations that seem to be consistently affected are infants, young children, and pregnant women, in the case of the China infant formula with melamine contamination, and in the case of the South Asian population, from chronic low-level exposure to lead through adulterated turmeric in the home kitchen.^{6,14} The implications of this for public-health prioritisation are clear: interventions aimed at quality control of infant-formula production and staple-spice supply chains will probably deliver disproportionately high morbidity-reduction benefits per unit of cost.

The other theme is socio-economic driver of the practices. In all the studies reviewed, it was not a single bad actor that was responsible for adulteration, but rather a combination of structural pressures in the supply chains, such as small profit margins, competitive undercutting, limited capacity for inspection, and even lack of awareness among small-scale processors about the toxicity of the dyes used when polishing turmeric.^{1,14} This indicates that regulatory measures focusing on punishment might be needed but are not necessarily enough: other levers have been pointed out throughout the literature, such as targeted producer training, low-cost testing technology and supply-chain transparency campaigns.

Development of detection technology has made a significant step forward, and more and more is able to detect adulterants that were once hard to differentiate from the real product. Adulteration has been successfully detected in turmeric, honey, and other high-risk commodities using Fourier-transform infrared spectroscopy, portable X-ray fluorescence devices, and high-performance liquid chromatography, as well as more recently, machine-learning-based classification models.^{15,18,19} The reviewed studies all point to the fact, however, that such technologies are still mostly confined to well-resourced laboratories and

testing regimes geared towards export markets, leaving domestic and informal markets, where the heaviest health impact seems to be, under-resourced and under-monitored.^{13,14}

There are a number of limitations that are inherent to a narrative synthesis of a heterogeneous evidence base for this review. The studies included are of diverse design, ranging from controlled animal toxicology studies to retrospective outbreak investigations to cross-sectional biomonitoring surveys, and so quantitative pooling of effect sizes is precluded. Examples of publication bias could also include the high visibility of outbreaks that are acute, compared with the larger but less apparent burden of chronic low dose exposures. Future studies would be valuable with longitudinal cohort studies quantifying the cumulative health effects of chronic low level exposure to the adulterants and with harmonised international reporting standards which will enable more robust quantitative synthesis in future reviews.

CONCLUSION

Adulteration of food products remains a significant preventable cause of both acute and chronic diseases in various population groups and milk, edible oils, spices and honey are the most consistently involved commodities. Pathological effects involve renal, hepatic, neurological, cardiovascular, and carcinogenic mechanisms, and infants and children are especially vulnerable to the negative impacts. This challenge will need coordinated effort among regulatory enforcement, available detection technology, producer education, and public awareness, and a more robust and standardized evidence base to inform future systematic and quantitative reviews.

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