



Safety of Imported Milk Powder: Contaminant Profiles, Detection Methods, and Regulatory Frameworks with Special Reference to Sri Lanka

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ABSTRACT

Milk powder is a globally traded dairy commodity of critical nutritional and economic importance, particularly in countries such as Sri Lanka where domestic dairy production is insufficient to meet consumer demand. However, imported milk powder is susceptible to a wide spectrum of contaminants including microbial pathogens (*Salmonella* spp., *Escherichia coli*, *Cronobacter sakazakii*), chemical adulterants (melamine, urea, starch), heavy metals (lead, cadmium, arsenic, mercury), mycotoxins (aflatoxin M1), antibiotic residues, and physical foreign matter, each posing distinct risks to public health. This review comprehensively examines the nature and classification of contaminants found in imported milk powder, the analytical detection technologies employed for their identification, and the regulatory and preventive frameworks relevant to Sri Lanka and international practice. Landmark contamination incidents including the 2008 Chinese melamine scandal, the 1955 Japanese arsenic poisoning, and Sri Lanka-specific episodes involving dicyandiamide and microbial adulterants are analysed to contextualise systemic vulnerabilities. Advanced detection methods including High-Performance Liquid Chromatography (HPLC), Gas Chromatography-Mass Spectrometry (GC-MS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Polymerase Chain Reaction (PCR), Enzyme-Linked Immunosorbent Assay (ELISA), Fourier Transform Infrared Spectroscopy (FTIR), and Near-Infrared Spectroscopy (NIR) are reviewed in terms of sensitivity, applicability, and limitations. Sri Lanka's regulatory architecture under the Food Act No. 26 of 1980, Sri Lanka Standards Institution (SLSI) standards, and Consumer Affairs Authority (CAA) mandates is critically evaluated. The review concludes with evidence-based recommendations to strengthen import controls, laboratory capacity, and public awareness to safeguard food safety.

Keywords: milk powder contamination; food safety; melamine adulteration; detection methods; Sri Lanka dairy regulation; mycotoxins

1. Introduction

Milk powder is a vital dairy product manufactured by evaporating liquid milk to remove almost all its moisture content, producing a stable, shelf-stable form that requires no refrigeration. Globally, it is one of the most widely traded dairy commodities, with world production exceeding 4.5 million metric tonnes annually (International Dairy Federation, 2018). In Sri Lanka, milk powder occupies a central position in household nutrition and industrial food processing, serving as a key ingredient in tea, confectionery, baked goods, infant formulas, and national supplementary feeding programs. Local dairy production satisfies approximately 40% of national requirements, making the country substantially dependent on imports, principally from New Zealand, Australia, India, and China (Mendis & Edirisinghe, 2014; Bogahawatte & Herath, 2006).

This heavy reliance on imported milk powder creates inherent vulnerabilities. Throughout the supply chain, from raw milk collection and spray drying at the factory to shipping, storage, and retail, numerous opportunities arise for the introduction of biological, chemical, and physical contaminants. The 2008 Chinese melamine scandal, in which an estimated 300,000 infants were affected after melamine was fraudulently added to dairy products to artificially elevate apparent protein content, brought global attention to the grave consequences of inadequate food safety governance (Jia et al., 2012; Pei et al., 2011). Sri Lanka was directly affected, with melamine-positive consignments detected between 2008 and 2010, and a separate dicyandiamide (DCD) contamination incident involving Fonterra products arising in 2013.

Despite the significance of these events, comprehensive peer-reviewed literature addressing the full contaminant spectrum in imported milk powder within the Sri Lankan context remains limited. This review addresses that gap by synthesising global and local evidence on (i) the classification and sources of contaminants in imported milk powder; (ii) validated analytical detection methodologies; (iii) health consequences of exposure; and (iv) regulatory and preventive frameworks, with the objective of informing evidence-based policy and practice.

2. Milk Powder: Composition and Types

Milk powder, also termed dried milk, is produced through spray drying or roller drying of pasteurised, concentrated milk. The process reduces moisture content to below 5%, dramatically extending shelf life without refrigeration and facilitating transport (Food and Agriculture Organization, 2013). Commercial categories include whole milk powder (WMP), skimmed milk powder (SMP), dairy whitener, and infant formula base, each differing in fat content, protein fractions, and fortification status. Nutritionally, milk powder retains the essential macro- and micronutrients of fresh milk, including high-quality caseins and whey proteins, lactose, calcium, phosphorus, and fat-soluble vitamins A and D (Tamminga et al., 2007). These attributes underpin its role as an affordable, accessible nutritional commodity in both developed and developing markets.

The compositional complexity of milk powder, particularly its high protein content, makes it a target for economic adulteration. Non-protein nitrogen-containing compounds such as melamine and urea can be added to artificially elevate Kjeldahl nitrogen readings, which are used as a proxy for protein content in routine quality testing. This fraudulent practice underpinned the 2008 melamine scandal and remains a critical concern in quality assurance (Handford et al., 2016).

3. Importance of Milk Powder in the Sri Lankan Market

In Sri Lanka, milk powder is deeply embedded in cultural and nutritional practice. Its primary domestic use is in tea preparation, a national beverage consumed multiple times daily across all socioeconomic strata. It is also indispensable in confectionery, bakery production, infant nutrition, and institutional feeding programs including the School Milk Programme. The Food and Agriculture Organization (2013) identifies milk powder as a strategic commodity for food security in regions with underdeveloped cold-chain infrastructure, a characterisation that applies to significant portions of rural Sri Lanka.

Domestic milk production is constrained by limited pastureland, smallholder farm fragmentation, insufficient veterinary services, and seasonal variability in feed quality (Bogahawatte & Herath, 2006). As a result, Sri Lanka imports over 60% of its dairy requirements, with milk powder representing the dominant import category. While this ensures market supply, it exposes consumers to the safety standards, and potential lapses, of multiple exporting nations. These trade dynamics make it imperative that import control mechanisms are robust, evidence-based, and aligned with international food safety norms.

4. Background of Contamination Issues

4.1 Definition and Classification of Contaminated Milk Powder

Contaminated milk powder is defined as powdered dairy product that contains any substance at concentrations exceeding established maximum residue limits (MRLs), or that harbours pathogenic microorganisms at levels rendering it unsafe for human consumption (Codex Alimentarius Commission, 2011). Contamination may be unintentional, arising from environmental sources, improper hygiene, equipment malfunction, or contaminated feed, or intentional, as in the case of adulteration for economic gain. The Codex Alimentarius Commission (2011) classifies food contaminants broadly into biological, chemical, and physical categories, a framework adopted throughout this review.

4.2 Global Incidents of Milk Powder Contamination

The historical record of milk powder contamination incidents underscores both the diversity of hazards and the catastrophic scale of consequences when food safety systems fail. The 1955 Morinaga milk arsenic incident in Japan resulted in contamination of dried milk with arsenic from industrial-grade sodium phosphate used as a stabiliser, poisoning over 12,000 infants and causing 130 deaths, with hundreds sustaining permanent neurological disabilities (Rota et al., 2009). This disaster catalysed the development of Japan's modern food safety regulatory infrastructure.

Five decades later, the 2008 melamine adulteration crisis in China became the largest documented food safety emergency in the dairy sector. Melamine, a triazine compound used industrially in plastics manufacture, was deliberately added to raw milk and infant formula to boost apparent protein content as measured by the Kjeldahl nitrogen method. Zhang et al. (2008) reported that over 300,000 infants developed urolithiasis (kidney stones), with more than 50,000 requiring hospitalisation and at least six fatalities confirmed. The incident triggered a global recall of Chinese dairy products and exposed systemic failures in regulatory oversight, third-party auditing, and supply chain transparency (Pei et al., 2011).

More recently, widespread detection of Aflatoxin M1 exceeding European Union maximum limits in infant formula imports has been reported through the Rapid Alert System for Food and Feed (RASFF), reflecting the persistent challenge of mycotoxin contamination in global dairy trade (Ye et al., 2019). Heavy metal contamination, particularly cadmium and lead, has been documented in commercial milk powders from multiple countries, attributed to industrial pollution affecting soil and animal feed (Kang et al., 2021).

4.3 Case Studies in Sri Lanka

Sri Lanka has encountered a series of contamination incidents that have tested its import safety architecture. Between 2008 and 2010, authorities detected melamine in milk powder consignments primarily from China. Several shipments were banned and destruction orders issued, while consumer confidence

in imported dairy products suffered significantly. Between 2013 and 2014, a separate controversy arose when Fonterra-branded products imported into Sri Lanka were found to contain dicyandiamide (DCD), a chemical used in nitrification inhibitors for agricultural fertilisers. Although DCD was not classified as acutely toxic at the concentrations detected, the incident prompted government-mandated product withdrawals and investigations by the Consumer Affairs Authority (CAA).

A third cycle of concern emerged between 2017 and 2019, when random testing conducted by the National Medicines Regulatory Authority (NMRA) and CAA identified microbial contamination, including coliform bacteria and Salmonella, in commercially available milk powder brands distributed in the local market. These findings indicated inadequate post-import monitoring and gaps in cold-chain management. Collectively, these episodes illustrate that Sri Lanka's food safety vulnerabilities span both import control and domestic market surveillance stages of the supply chain.

5. Types of Contaminants in Imported Milk Powder

Imported milk powder is susceptible to a diverse array of contaminants, broadly categorised into microbial, chemical, and physical types. Table 1 provides a comparative overview of these categories, including representative examples, sources, and associated health impacts.

Table 1. Classification of contaminants in imported milk powder: examples, sources, and health impacts.

Type	Examples	Source / Cause	Health Impact
Microbial	<i>Salmonella</i> spp., <i>E. coli</i> , <i>Listeria monocytogenes</i> , <i>Cronobacter sakazakii</i> , Coliforms	Poor hygiene, inadequate heat treatment, cross-contamination	Gastroenteritis, septicaemia, neonatal meningitis, mortality
Chemical – Adulterants	Melamine, urea, starch, detergents, vegetable proteins	Intentional adulteration for economic gain	Renal failure, urolithiasis, developmental impairment
Chemical – Heavy Metals	Lead (Pb), Cadmium (Cd), Arsenic (As), Mercury (Hg)	Contaminated feed, industrial pollution, soil uptake	Neurotoxicity, carcinogenesis, chronic organ damage
Chemical – Mycotoxins	Aflatoxin M1, Ochratoxin A, Zearalenone	Mould-contaminated animal feed consumed by dairy cattle	Hepatotoxicity, carcinogenicity (IARC Group 1), immunosuppression
Chemical – Antibiotic Residues	Beta-lactams, tetracyclines, sulfonamides	Overuse of veterinary antibiotics in dairy farming	Antimicrobial resistance, allergic reactions
Physical	Metal fragments, plastic, glass, insects, dust	Poor handling, packaging defects, equipment wear	Choking, internal injury, secondary infection

5.1 Microbial Contaminants

Pathogenic microorganisms represent the most immediate public health threat in milk powder. Despite the lethality of spray drying to most vegetative bacteria, spore-forming organisms such as *Bacillus cereus* and *Clostridium* spp. may survive and proliferate during storage or rehydration. *Cronobacter sakazakii* (formerly *Enterobacter sakazakii*) is of particular concern in powdered infant formula, causing severe neonatal meningitis and septicaemia with case-fatality rates reaching 40-80% (He & Bhatt, 2018). Wang et al. (2017) demonstrated the utility of multiplex PCR for simultaneous detection of *Cronobacter sakazakii* and *Salmonella* in powdered infant formula, achieving detection limits of 1 CFU/g following 6-hour enrichment. *Salmonella* spp. and *Listeria monocytogenes* can re-contaminate product through post-processing environmental exposure (Rota et al., 2009; Shimelis et al., 2015).

5.2 Chemical Contaminants

Chemical contamination encompasses several subcategories. Intentional adulterants including melamine, urea, starch, vegetable proteins, and detergents are added to increase product volume or manipulate analytical protein measurements. Melamine's high nitrogen content (66.6% by mass) makes it particularly effective at inflating Kjeldahl protein readings (Jia et al., 2012; Abedini et al., 2021). Urea and detergents are similarly employed to artificially elevate protein or density values (Mukherjee & Bhattacharya, 2019).

Heavy metals including lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) may enter milk through contaminated pasture, feed, water, or processing equipment. Gurbuz et al. (2018) detected cadmium concentrations exceeding recommended limits in 15% of commercial milk powder samples from multiple countries. Kang et al. (2021) reported elevated Pb and As levels in Chinese raw milk associated with proximity to mining operations. Aflatoxin M1, the hydroxylated metabolite of aflatoxin B1 produced by *Aspergillus* species in mould-contaminated feed, is not eliminated by pasteurisation or

spray drying (Van der Fels-Klerx et al., 2016; Ye et al., 2019). Antibiotic residues from veterinary use are a growing concern with implications for antimicrobial resistance propagation (Niknejad et al., 2017).

5.3 Physical Contaminants

Physical contaminants in milk powder include metallic fragments from processing equipment, plastic particles from packaging machinery, glass from broken inspection windows, insect parts, and extraneous particulate matter. These typically arise from poor manufacturing practices, inadequate equipment maintenance, or inadequate environmental controls during open-air processing or repackaging operations. While not chemically toxic, physical contaminants pose choking, lacerative, and secondary infection risks, particularly in infants (Saltmarsh, 2015).

6. Health Risks and Consequences

The health consequences of consuming contaminated milk powder range from acute self-limiting episodes to chronic, irreversible organ damage. Acute effects include nausea, vomiting, abdominal pain, and diarrhoea arising from ingestion of microbial pathogens or chemical irritants. These presentations are more severe in immunocompromised individuals, infants, pregnant women, and the elderly (World Health Organization, 2019).

Chronic exposure to chemical contaminants carries substantial long-term risk. Melamine causes renal calculi through precipitation of melamine-cyanuric acid complexes in the renal tubular system, as documented in the 2008 Chinese outbreak (Zhang et al., 2008). Lead accumulation impairs neurological development in infants and young children, with no safe threshold of exposure established by regulatory bodies. Cadmium is a nephrotoxin that bioaccumulates over decades. Aflatoxin M1 is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC), with hepatocellular carcinoma identified as the principal long-term malignancy (Ye et al., 2019). Antibiotic residues contribute to selection pressure for antimicrobial-resistant bacteria, a major global health security threat (United Nations Codex Alimentarius, 2020).

Infants consuming contaminated powdered infant formula are disproportionately vulnerable because milk powder may constitute their sole or primary nutritional source, exposure is sustained over critical developmental windows, and their immature renal and hepatic systems have limited detoxification capacity. The World Health Organization (2019) estimates that 600 million people fall ill annually due to contaminated food, with dairy products implicated in a significant proportion of reported outbreaks.

7. Detection and Testing Methods

A multi-method analytical approach is required to address the breadth of contaminants possible in imported milk powder. Table 2 summarises the principal detection technologies, their target contaminants, analytical sensitivity, and operational characteristics.

Table 2. Analytical methods for detection of contaminants in imported milk powder: targets, sensitivity, and operational comparison.

Method	Target Contaminant	Sensitivity / LOD	Advantages & Limitations
Total Plate Count (TPC)	General bacterial load	≥ 1 CFU/mL	Simple, low cost; slow (24-72 h); no species identification
PCR / Real-time qPCR	<i>Salmonella</i> , <i>Listeria</i> , <i>E. coli</i> , <i>Cronobacter</i>	1-10 CFU/g (with enrichment)	Rapid, highly specific; requires equipment and expertise
ELISA	Toxins, melamine, allergens	$\mu\text{g/kg}$ range	High-throughput; potential antibody cross-reactivity
HPLC / HPLC-UV	Melamine, aflatoxins, antibiotics, pesticides	0.05-0.5 mg/kg	Precise and reproducible; complex sample preparation required
GC-MS	Pesticides, volatiles, heavy metals	$\mu\text{g/kg}$ to ng/kg range	Gold-standard confirmation; expensive, time-intensive
ICP-MS	Pb, Cd, As, Hg, Cr (heavy metals)	ng/L to pg/L	Ultra-sensitive multi-element; high equipment cost
FTIR Spectroscopy	Adulterants: urea, starch, detergents, melamine	$> 0.1\%$ (w/w)	Rapid, non-destructive; requires reference spectral database
NIR Spectroscopy	Protein, fat, moisture; general adulteration	$> 0.5\%$ (w/w)	Real-time QC, non-contact; lower specificity than FTIR

Method	Target Contaminant	Sensitivity / LOD	Advantages & Limitations
X-ray Inspection	Glass, stones, dense plastics, bone fragments	Objects > 0.5 mm (density-dependent)	In-line inspection of sealed packs; cannot detect soft low-density plastics

7.1 Microbiological Testing

7.1.1 Culture-Based Methods

Total Plate Count (TPC) on plate count agar provides an index of overall bacterial contamination and product hygiene. Selective and differential media, including Salmonella-Shigella agar and MacConkey agar, enable isolation and presumptive identification of specific pathogens. The Most Probable Number (MPN) technique is applied for quantitative estimation of coliform bacteria at low concentrations. While culture methods are considered regulatory gold standards, they require 24-72 hours and are unsuitable for rapid screening of perishable consignments (de Boer et al., 2010).

7.1.2 Molecular Methods: PCR and Real-Time qPCR

Polymerase Chain Reaction (PCR) amplifies specific pathogen DNA sequences with high sensitivity and specificity. Real-time quantitative PCR enables simultaneous detection and quantification, achieving detection limits of 1-10 CFU/g following a 6-hour pre-enrichment step (Wang et al., 2017). Multiplex PCR platforms allow concurrent screening for multiple pathogens in a single reaction, reducing cost and turnaround time. This technology is increasingly adopted by regulatory authorities for confirmatory testing of high-risk import consignments.

7.1.3 Immunological Methods: ELISA

Enzyme-Linked Immunosorbent Assay (ELISA) exploits antigen-antibody interactions for detection of microbial toxins, melamine, and allergens. ELISA offers high throughput and moderate sensitivity, making it suitable for initial screening of large numbers of samples. Cross-reactivity between structurally similar compounds can reduce specificity, necessitating confirmatory testing by chromatographic methods (Lutter et al., 2011).

7.2 Chemical Contaminant Detection

7.2.1 High-Performance Liquid Chromatography (HPLC)

HPLC is the benchmark method for quantitative determination of melamine, aflatoxins, antibiotic residues, and pesticides in milk powder, achieving limits of detection in the range of 0.05-0.5 mg/kg. Lutter et al. (2011) validated an HPLC-UV method for melamine detection in powdered infant formula, demonstrating mean recoveries exceeding 90%. Tandem mass spectrometry coupling (LC-MS/MS) further enhances specificity and reduces detection limits to sub-µg/kg levels (Abedini et al., 2021).

7.2.2 Gas Chromatography-Mass Spectrometry (GC-MS)

GC-MS provides definitive identification and quantification of volatile and semi-volatile chemical contaminants including pesticides, mycotoxins, and industrial solvent residues. Sun et al. (2020) demonstrated GC-MS-based metabolite profiling of milk powder for simultaneous authenticity screening and quality assessment, identifying characteristic volatile fingerprints that distinguished genuine from adulterated samples. GC-MS is recognised as a gold-standard confirmatory technique but requires skilled personnel, costly instrumentation, and extensive sample preparation.

7.2.3 Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

ICP-MS offers the highest sensitivity for multi-element heavy metal analysis, with detection limits in the pg/L to ng/L range for Pb, Cd, As, Hg, and other trace elements simultaneously. Kang et al. (2021) employed ICP-MS to demonstrate significant regional variation in heavy metal profiles of Chinese raw milk. The technique requires acid digestion sample preparation but provides comprehensive elemental profiles unachievable by any other single method.

7.2.4 UV-Visible Spectrophotometry

UV-visible spectrophotometry provides a cost-effective, rapid screening tool for melamine and selected chemical adulterants based on characteristic absorbance profiles. While offering lower sensitivity and specificity compared to chromatographic methods, it serves as a valuable first-tier screening technique in resource-limited settings, enabling preliminary identification of suspect samples for confirmatory analysis.

7.3 Physical Contaminant Detection

Physical hazard detection combines several complementary technologies. Visual inspection and sieving identify large visible foreign bodies at production level. In-line metal detectors operating on electromagnetic induction principles detect ferrous, non-ferrous, and stainless-steel fragments during processing. X-ray inspection systems provide the broadest detection capability, identifying dense objects including glass, stones, calcified bone, and dense plastics within sealed packaging without interrupting the production line. The sensitivity of X-ray systems depends on object density relative to the surrounding matrix, with low-density soft plastics remaining challenging to detect reliably (Saltmarsh, 2015).

7.4 Adulteration Detection Using Spectroscopic Methods

Fourier Transform Infrared (FTIR) spectroscopy analyses the unique mid-infrared absorption fingerprint of a sample, enabling detection of structural adulterants including urea, starch, vegetable proteins, detergents, and melamine at concentrations above approximately 0.1% (w/w). Cattaneo and Holroyd (2013) reviewed FTIR and NIR applications in milk and milk powder adulteration detection, concluding that chemometric data treatment substantially improves discrimination accuracy beyond visual spectral comparison. Near-Infrared (NIR) spectroscopy provides rapid, non-destructive assessment of protein, fat, lactose, and moisture content and enables broad-spectrum adulteration profiling. NIR is particularly valuable for real-time quality control in production lines. Pizzoferrato et al. (2014) demonstrated that principal component analysis combined with NIR data could effectively distinguish genuine from adulterated milk powder samples in a blind trial.

8. Preventive Measures

Prevention of milk powder contamination requires a multi-barrier approach encompassing pre-export assurance, import controls, supply chain management, and post-market surveillance. Table 3 presents an integrated framework of preventive measures, their purposes, and the responsible authorities in the Sri Lankan context.

Table 3. Preventive measures for contaminated imported milk powder: purpose and responsible authorities.

Preventive Measure	Purpose	Responsible Authority
Mandatory Health Certificate from exporting country	Verifies conformance to safety standards at source	Sri Lanka Customs / Ministry of Health
SLS 731 Compliance Testing	Ensures compositional and hygienic requirements are met	Sri Lanka Standards Institution (SLSI)
Advanced Laboratory Infrastructure (HPLC, ICP-MS, PCR)	Enables precise multi-contaminant screening	Industrial Technology Institute (ITI) / Medical Research Institute (MRI)
Controlled Cold-Chain Storage and Transportation	Prevents microbial growth and chemical degradation post-import	Importers; Consumer Affairs Authority (CAA)
Regular Market Surveillance and Random Sampling	Detects post-market contamination and counterfeit products	CAA; Food Safety Officers
International Collaboration and RASFF Membership	Enables rapid intelligence-sharing on global food safety alerts	Ministry of Health; Codex Contact Point
Public Awareness on Labelling and Safe Storage	Empowers consumers to make informed decisions	CAA; Ministry of Health
Promotion of Local Dairy Production	Reduces dependence on potentially unsafe imported products	Ministry of Agriculture; Livestock Development Board

A risk-based import control system, in which inspection frequency and testing scope are determined by the historical compliance record of the exporting country and supplier, is recommended by Codex Alimentarius (2011) and implemented effectively in the European Union, Australia, and Singapore. Adoption of a digital, risk-tiered surveillance system would substantially enhance the efficiency and effectiveness of border controls in Sri Lanka without creating unnecessary delays to compliant consignments.

9. Regulatory Framework

9.1 Food Act No. 26 of 1980

The Food Act No. 26 of 1980 is the primary statutory instrument governing food safety in Sri Lanka. It prohibits the importation, manufacture, sale, or distribution of food containing any deleterious substance injurious to health, food unfit for human consumption, or adulterated food. The Act confers authority on the Minister to promulgate subsidiary regulations governing labelling, packaging, composition, and importation requirements for specific food categories. Enforcement is vested in Authorised Officers and Public Health Inspectors at the local authority level.

9.2 Sri Lanka Standards Institution (SLSI)

The SLSI administers the national standard SLS 731, which specifies compositional, microbiological, and safety requirements for milk powder marketed in Sri Lanka. Compliance with SLS 731 is a prerequisite for import clearance. The SLSI conducts batch testing of import consignments and issues SLS certification for compliant products (Sri Lanka Standards Institution, 2015).

9.3 Sri Lanka Customs Department

The Customs Department enforces import restrictions at the point of entry, requiring importers to present valid SLSI permits, health certificates from the exporting country's competent authority, and documentary evidence of compliance with applicable standards before release of consignments. Coordination between Customs, SLSI, and the Ministry of Health is essential for effective border control.

9.4 Consumer Affairs Authority (CAA)

Established under the Consumer Affairs Authority Act No. 09 of 2003, the CAA is empowered to conduct market surveillance, investigate consumer complaints, and issue directives to manufacturers and traders regarding labelling, packaging, and quality. The CAA has authority to initiate product recalls and impose penalties on non-compliant parties, providing a complementary layer of protection to border controls.

9.5 Comparison with International Regulatory Frameworks

Sri Lanka's regulatory architecture, while covering fundamental requirements, lacks several features present in more mature food safety systems. The European Union's Rapid Alert System for Food and Feed (RASFF) enables real-time, cross-border notification of food safety incidents. Australia's Food Standards Australia New Zealand (FSANZ) maintains publicly accessible MRLs for over 300 contaminants in dairy products. Adoption of analogous mechanisms in Sri Lanka, including electronic import data sharing, harmonised MRL schedules aligned with Codex, and published surveillance data, would represent significant advances (Tripathy et al., 2018).

10. Comparative Analysis: Global and Sri Lankan Incidents

Table 4 provides a structured comparison of major milk powder contamination incidents at the global and Sri Lankan levels, illustrating the diversity of contaminant types, the scale of public health impact, and the regulatory responses implemented in each case.

Table 4. Comparative analysis of notable milk powder contamination incidents: global and Sri Lankan perspectives.

Country	Year	Contaminant	Impact & Outcome	Regulatory Response
China	2008	Melamine (infant formula)	>300,000 infants; 6 deaths; 50,000 hospitalised	Global recall; criminal prosecution; regulatory overhaul
Japan	1955	Arsenic (industrial-grade sodium phosphate)	>12,000 infants poisoned; 130 deaths; lasting disabilities	Stricter food manufacturing regulations introduced
Sri Lanka	2008-2010	Melamine (imports from China)	Shipments banned; consumer trust severely eroded	Import bans; enhanced port-of-entry testing
Sri Lanka (Fonterra)	2013	Dicyandiamide (DCD)	Market withdrawal; government scrutiny; consumer alarm	CAA investigation; product labelling review
Sri Lanka	2017-2019	Coliforms, Salmonella	NMRA/CAA random testing revealed non-	Batch recalls; market surveillance intensified

Country	Year	Contaminant	Impact & Outcome	Regulatory Response
			compliance in retail market	
European Union	Multiple	Aflatoxin M1 (infant formula imports)	RASFF alerts; product withdrawals across member states	Stricter MRL enforcement; supplier audits
Egypt	2016	Heavy metals, pathogens in SMP	Elevated Pb, Cd, Aflatoxin M1 and coliform exceedances	Increased import testing frequency

11. Conclusion

This review has demonstrated that imported milk powder is susceptible to a wide and diverse spectrum of contaminants, each associated with distinct public health risks and requiring specific analytical methodologies for detection. The evidence base drawn from global and Sri Lankan incidents underscores that contamination is not merely a theoretical risk but a recurring reality with documented consequences including infant mortality, chronic renal disease, developmental impairment, and antimicrobial resistance. The 2008 Chinese melamine scandal, the Fonterra DCD incident in Sri Lanka, and microbial contamination findings between 2017 and 2019 illustrate the multi-dimensional nature of this challenge.

A portfolio of validated analytical techniques including HPLC, GC-MS, ICP-MS, PCR, ELISA, FTIR, and NIR spectroscopy is available to address this contaminant diversity. Deployment of these techniques in a tiered, risk-based framework, where rapid screening methods are applied universally and confirmatory methods are triggered by initial findings, represents the most resource-efficient approach for regulatory authorities. Sri Lanka's regulatory framework anchored by the Food Act No. 26 of 1980, SLSI standard SLS 731, and CAA market surveillance provides a structural foundation for food safety governance; however, this framework requires enhancement through upgraded laboratory infrastructure, formalised risk-tiered import surveillance aligned with Codex principles, and integration with international rapid alert systems. A safer, more transparent milk powder supply chain for Sri Lanka demands coordinated commitment from government agencies, the private sector, academic institutions, and consumers alike.

12. Recommendations

Based on the evidence synthesised in this review, the following recommendations are proposed for policy-makers, regulatory authorities, and food safety practitioners in Sri Lanka:

- 1. Establish a risk-tiered import surveillance system:** Implement an electronic pre-arrival notification and risk-scoring mechanism for all imported dairy products, integrating historical compliance data of suppliers and exporting countries.
- 2. Upgrade analytical laboratory infrastructure:** Equip the Industrial Technology Institute (ITI) and Medical Research Institute (MRI) with ICP-MS, LC-MS/MS, and real-time PCR platforms, and develop national reference methods aligned with Codex and AOAC standards.
- 3. Harmonise MRLs with international standards:** Align maximum residue limits for heavy metals, mycotoxins, pesticides, and antibiotic residues in milk powder with Codex Alimentarius and EU benchmarks.
- 4. Subscribe to international rapid alert systems:** Explore formal participation in or data-sharing arrangements with RASFF to receive early warning intelligence on globally circulating food safety threats.
- 5. Strengthen post-market surveillance:** Mandate quarterly random sampling and testing of commercially available milk powder brands through CAA, with public disclosure of results to promote market transparency.
- 6. Invest in domestic dairy production:** Provide structured financial and technical support to smallholder dairy farmers to increase domestic production and reduce dependence on imported milk powder.
- 7. Implement food safety education:** Engage the Ministry of Education and consumer advocacy organisations to integrate food safety literacy into national curricula and community health programs.

Authors' Contributions

GGPM Abeweera and ADM Bandara conducted the review and prepared the manuscript; WMPW Kumari supervised and edited the manuscript.

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Ethical Consideration

Not applicable; this review did not involve human participants, animals, or primary data collection.

Competing Interest

The authors declare no competing interests.

AI Declaration Statement

Artificial intelligence-assisted tools were used only to support language editing, grammar correction, and improvement of clarity and readability of the manuscript.

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