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Microplastic Contamination in Milk and Dairy Products: Present and Future

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Materials and Methods

This research review was based on the following:

Period: 15 years from 2010 to 2025

Databases:

- Scopus
- Web of Science
- NCBI
- ProQuest
- Google Scholar
- ResearchGate, etc.

Keywords: Microplastics, Nanoplastics, Raw Milk, Dairy Products, Health Risk, Toxicity, Food Contamination, Polymer, Mitigation Strategies

What are Microplastics and Nanoplastics?

As per International Organization for Standardization (ISO)

Microplastics (MPs): Tiny plastic particles (<5 mm) found in synthetic clothes, toothpaste, face scrubs, and plastic containers.

Nanoplastics (NPs): Even smaller plastic particles (<1 µm) that can enter the bloodstream and cells.

Differing Definitions of MPs and NPs

- No harmonized definition of MPs and NPs (EFSA, 2021)
- 1 micrometer (µm) = 1000 nanometers (nm)
- 1 nm = 0.001 µm & 100 nm = 0.1 µm

Agency	Microplastics (MPs)	Nanoplastics (NPs)
Environmental Protection Agency (EPA)	5 mm – 0.001 µm	< 1 µm
Food and Drug Administration (FDA)	5 mm - 1 µm	1 µm - 0.001 µm
Consumer Product Safety Commission (CPSC)	No definition	No definition
European Food Safety Authority (EFSA)	5 mm – 1 µm	0.1 µm - 0.001 µm

Data source: Ho et al., (2024). https://doi.org/10.1016/j.marpolbul.2024.116907

Primary Exposure Routes

Ingestion and Inhalation

(Cox et al., 2019; Prata et al., 2020)

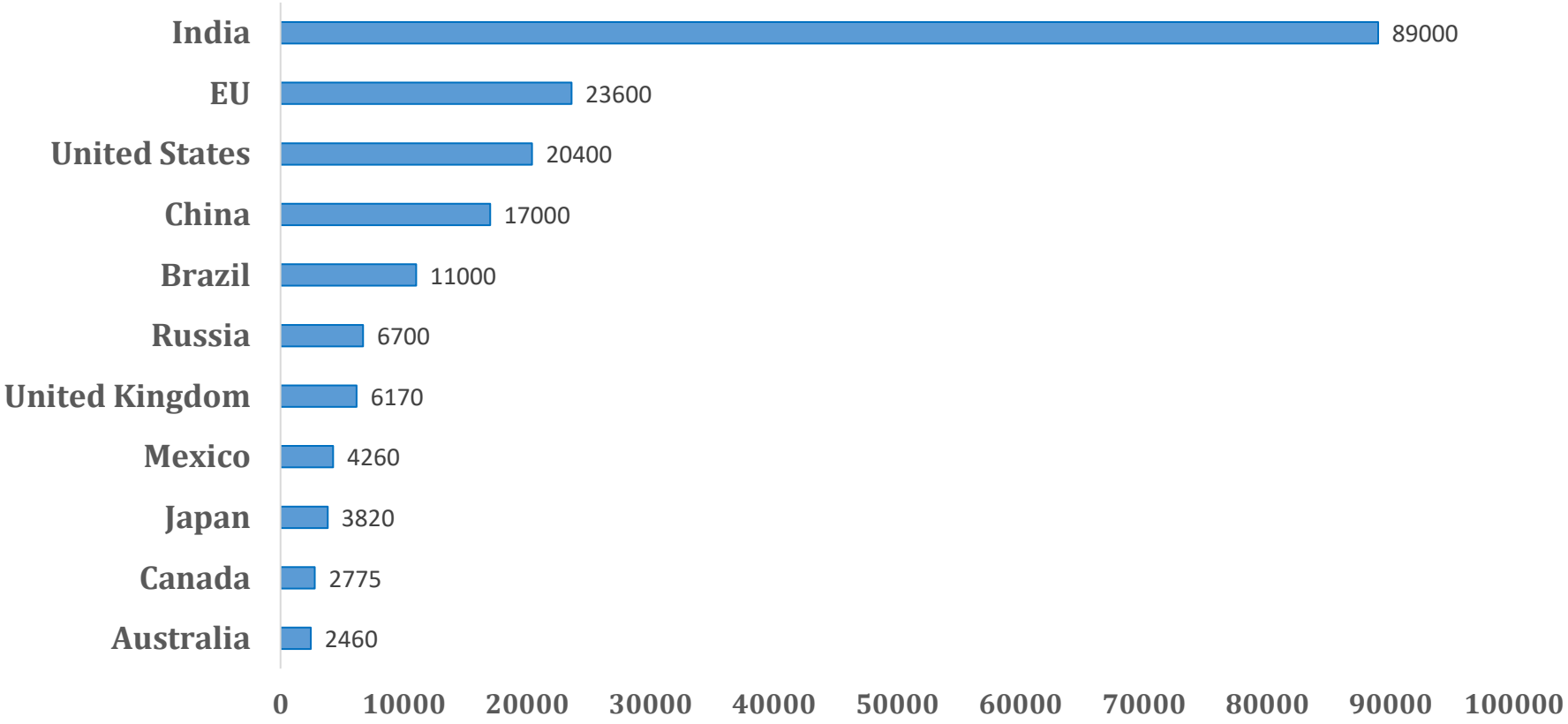
Approximately 74,000 - 211,000 microplastic particles are annually ingested by Americans via food and inhalation

(Cox et al., 2019)

MP & NP Contamination Levels in Commonly Consumed Goods

Source	MP/NP Concentration	Key Studies
Raw Milk	48 to 650 MPs/100 mL	Zhang et al., 2023
Sea Salt	74 - 1155 MPs/kg	Thiele et al., 2023
Plastic Tea Bags	11.6 billion MPs/cup and 3.1 billion NPs/cup	Hernandez et al., 2019

Annual Consumption of Fluid Cow Milk Worldwide 2024 (in 1000 metric tons)



Data source: https://www.statista.com/statistics

Global Dairy Trade

- Global dairy trade volumes = projected growth by 12% by 2034
- Most traded = Milk powders and Butter (Shelf-stable & most likely to carry MP contamination)
- Rising demand = Met through Imports [in China, the Near East and North Africa (NENA), & SE Asia]
- Contamination isn't local if the product is global

Product	Main Exporters (2022-2024)	Main Importers (2022-2024)
Whole Milk Powder	New Zealand (59% of global exports); EU; Argentina	NENA, China, Sub-Saharan Africa
Skim Milk Powder	EU and USA (78% of global exports combined)	Southeast Asia, NENA, Rest of the World, High-income countries
Butter	New Zealand (46%); EU	High-income countries, NENA, China

Source: OECD/FAO (2025), "OECD-FAO Agricultural Outlook", OECD Agriculture statistics (database), http://data-explorer.oecd.org/s/1hc.

Concentration in Milk Products

Type of dairy product	Volume	Reference
Brand Milk	52 – 1004 microplastics per liter	Da Costa Filho et al., 2021
Cheese	6.5 ± 2.3 microplastics per gram	Di Fiore et al., (2024)
Yoghurt	50 – 610 particles per liter	Zipak et al., (2022)
Ayran	26 – 43 particles per 100 ml	Buyukunal et al., (2023)
Baby formula/ powdered milk	4 – 17 particles per 100 grams	Zhang et al., (2023)

Methods of Detection

- Visual analysis
- Fourier-transform infrared spectrometry (FTIR)
- Raman spectroscopy
- Pyrolysis-gas chromatography-mass spectrometry (Py-GC-MS)

(Yu Chen et al., 2024)

- Laser spectroscopy
- Hyperspectral imaging

(Fuentes et al., 2022)

- **Common Shapes and Colors:** Fragments and fibers, primarily blue, red, black, and gray—indicative of synthetic textiles, industrial dyes, and packaging

Microplastics Types and Their Sources in Dairy Systems

Polymer	Primary Sources in Dairy
Polystyrene (PS)	Plastic cups, single-use milk containers.
Polyvinyl chloride (PVC)	Tubing, gaskets, and flexible hoses in milking/processing equipment.
Polypropylene (PP)	Bottle caps, yogurt lids, cheese wrappers.
Polyether sulfone (PES) & Polysulfone (PSU)	Leaching from ultrafiltration membranes used in milk processing (e.g., protein separation).
Polyethylene terephthalate (PET)	Milk bottles, synthetic fibers from dairy worker uniforms contaminating processing lines.
Nylon-6	Strainers, filters, and textile fibers from dairy farm/processing environments.
Ethylene-vinyl acetate (EVA)	Seals in packaging, milking machine parts.

Role of Plastic Additives & Their Toxicological Relevance

MPs often carry chemical additives that leach into milk, especially under heat or mechanical stress

Additive Type	Function	Health Concern
Phthalates	Plasticizers for flexibility	Endocrine disruption, reproductive toxicity
Bisphenols (BPA)	Resin component	Hormone mimicry, carcinogenicity
Lead, Cadmium	Stabilizers	Neurotoxicity, organ damage
PBDEs	Flame retardants	Developmental and liver toxicity
Azo dyes	Coloring agents	Carcinogenic potential

Microplastics and Digestion: Disruption of Milk Nutrient Absorption

Protein Digestion Impairment: (Yee et al., 2021; Zhu et al., 2024)

- MPs, especially PS, reduce pepsin activity → accumulation of longer peptides (10–35 kDa)
- MPs bind to proteins, thus, reducing the formation and uptake of absorbable 2–9 kDa fragments

Lipid Digestion Impairment: (Yee et al., 2021)

- PS alters gastric lipase structure and function
- Lipid breakdown reduced by ~30%
- Adsorption of lipids onto MPs may transport toxins across intestinal barriers

Gut Microbiota and Metabolic Disruption

Chronic ingestion of MPs disrupts the gut ecosystem and contributes to metabolic disorders (Yang et al., 2020; You et al., 2019; Al Mamum et al., 2023)

- **Microbiota Dysbiosis:** PS and PP alter gut microbial composition
- **Mechanism:** MPs adsorb digestive enzymes and release inflammatory additives
- **Outcomes:**
  - Lipid metabolism disorders
  - Obesity and insulin resistance

Prenatal and Infant Exposure to Microplastics

Placental and Neonatal Exposure: (Braun et al., 2021; Gruber et al., 2020)

- MPs detected in human placenta and meconium - Suggests prenatal translocation facilitated by protein-binding mechanisms

Breast Milk Contamination: (Adjama et al., 2024)

- MPs and additives ingested by infants through lactation
- Adjama et al. (2024) confirmed MP presence in 78% of breast milk samples (n = 42) from urban mothers, with PE, PP, and PET as main types. Average: 12 MPs per 100 mL
- Toxicological outcomes in infants are not fully understood

Infant Formula as a Vector:

- High temperatures and reconstitution practices significantly increase MP concentration

Reproductive System Effects

Gonadal Toxicity (Testes & Ovaries) (Al Mamum et al., 2023; Ye et al., 2024; Zhu et al., 2024)

- **In Males**:
  - **Spermatogenesis impairment**: Decreased sperm count, motility, and viability
  - **Testicular inflammation**: Oxidative stress and apoptosis in Sertoli/Leydig cells
- **In Females**:
  - **Ovarian follicle atresia**: Reduced oocyte quality and follicular reserve
  - **Ovulation disruption**: Altered LH/FSH ratios

Transgenerational Effects (Al Mamum et al., 2023; Ye et al., 2024)

- MPs/NPs can **cross placental barriers**, causing:
  - **Fetal developmental defects** (e.g., cryptorchidism, delayed puberty)
  - **Epigenetic changes** (DNA methylation in germ cells)

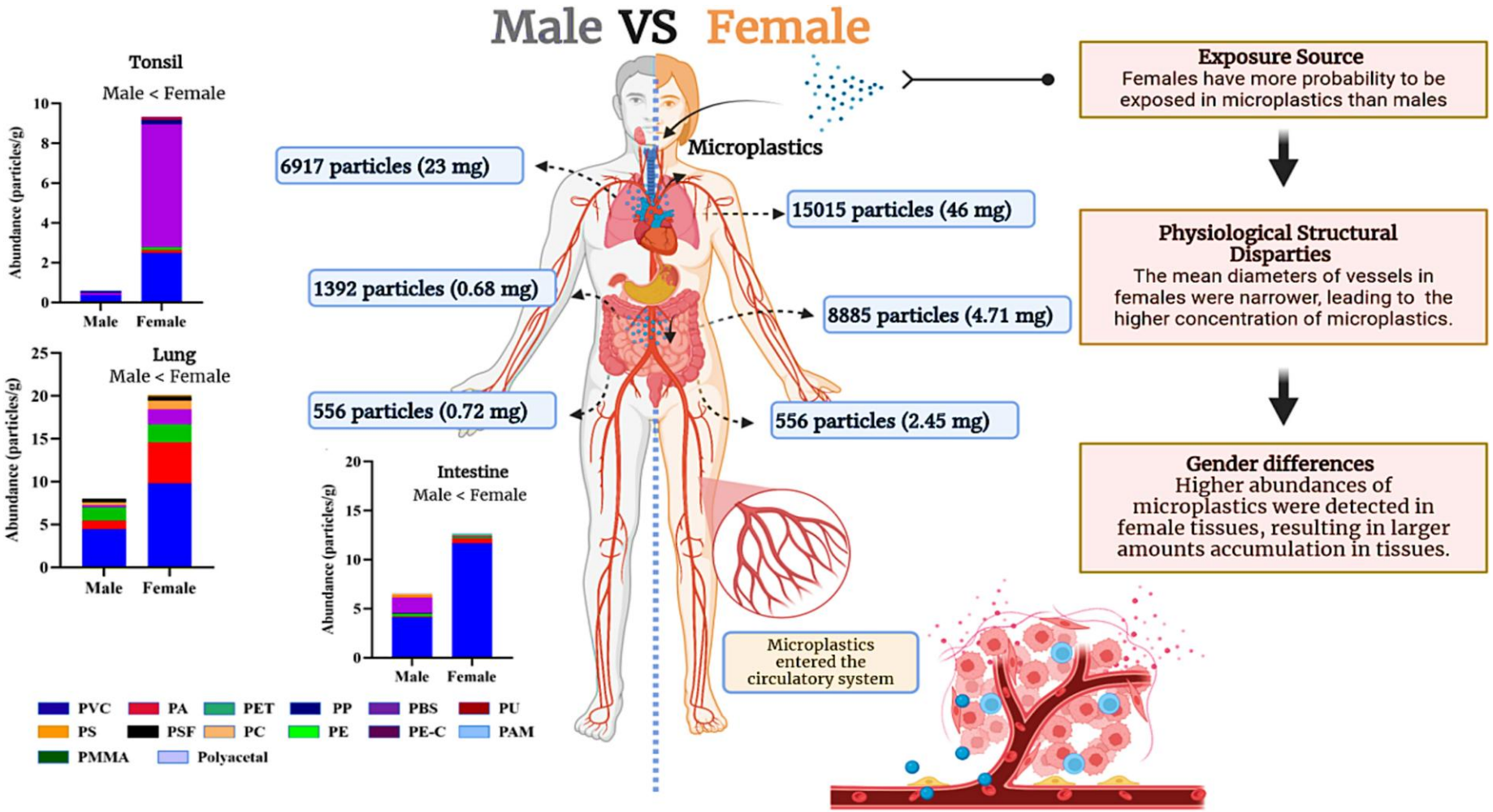
Mechanisms of Damage (Al Mamum et al., 2023; Ye et al., 2024; Zhu et al., 2024)

- **Oxidative stress**: ROS overproduction damages reproductive cells
- **Inflammation**: NF-κB and cytokine upregulation (e.g., TNF-α, IL-6)
- **Autophagy/apoptosis**: MPs trigger cell death in gonads

Carcinogenic Risks of Microplastic Contamination

- **Carcinogenic Additives:** Vinyl chloride (PVC) and synthetic dyes linked to mutagenesis
- The estimated cancer risk (in terms of the lifetime of microplastic ingestion): $1.13\times 10^{-5} – 1.28 \times 10^{-5}$, higher than the recommended value of 10^{-6} (Sharma et al., 2020)

- **Mechanisms:** (Al Mamum et al., 2023; Sharma et al., 2020; Zhu et al., 2024)
  - Chronic inflammation from MP accumulation
  - Oxidative DNA damage
  - Increased mutation rates and tumorigenesis



PA: polyamide; PAM: polyacrylamide; PBS: polybutylene succinate; PC: polycarbonate; PE: polyethylene; PP: polypropylene; PET: polyethylene terephthalate; PMMA: polymethyl methacrylate (PMMA); PS: polystyrene; PU: polyurethane; PVC: polyvinyl chloride

Zhu et al. (2024). https://doi.org/10.1016/j.scitotenv.2024.170004

Prevention Strategies

Industrial Measures:

- Replace plastic filtration membranes with ceramic or stainless steel
- Eliminate water addition practices that may introduce environmental MPs
- Switch to glass or metal packaging materials

Policy Recommendations

Policy Interventions:

- Uniform definition of MPs & NPs
- Harmonize protocols, instrumentation, and data processing - ensure reliable and comparable results across studies
- Set global thresholds for allowable MP levels in dairy products
- Mandate labeling of MP-safe food-grade plastics
- Fund interdisciplinary research on MPs in human nutrition

Consumer Recommendations

1. Choose Packaging Wisely

- **Avoid plastic containers**: Opt for milk in **glass bottles, cartons (paperboard), or stainless steel**
- **Check recycling codes**: Avoid #3 (PVC), #6 (polystyrene), and #7 (polycarbonate) plastics - prone to leaching

2. Minimize Heat Exposure

- **Never microwave milk in plastic containers**: Use glass or ceramic instead
- **Store dairy away from heat/sunlight**

Consumer Recommendations

3. Prefer fresh over ultra-processed dairy

4. Prioritize Organic and Local Sources

- **Organic dairy farms**: May have lower MP contamination due to restricted plastic feed packaging and reduced synthetic inputs
- **Local farms with glass bottles**: Reduces transport/storage time in plastic

Consumer Recommendations

5. **Limit Consumption of Highly Processed Dairy**
   - Avoid single-serving creamers/cheese spreads
   - Choose bulk or unwrapped cheese
6. **Support Brands Committed to Reducing Plastics**
   - Look for companies using **biodegradable packaging** (e.g., PLA corn-based plastics) or **zero-waste initiatives**
7. **Advocate for Transparency**
   - Demand **MP/NP testing labels** (e.g., "microplastic-free certification") from dairy producers

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Thank you for your attention!

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