ORIGINAL ARTICLE

Occurrence of Microplastics in Formula-Type and Puree-Type Commercial Infant Foods (CIFs) and its Potential Health Risk to Consumers

Yu Bin Ho[1], Puteri Dafinah Azurin Azman[1], Sitti 'Aaisyah 'Afiyfah Abdullah[1], Sarva Mangala Praveena[1]

[1] Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia

ABSTRACT

Introduction: Microplastics (MPs), defined as particles <5 mm, are emerging food contaminants of global concern. Infants are particularly vulnerable to MP exposure due to their higher intake of food relative to body weight, yet little is known about MPs in infant food. **Materials and Methods:** Seven commonly consumed brands each of formula-type and puree-type commercial infant foods (CIFs) in Malaysia were analyzed (42 samples, triplicates). Samples were digested, sieved, filtered, and examined microscopically to determine MP abundance, shape, color, and size. Contamination levels and potential risks were assessed using the Microplastic Contamination Factor (MPCF) and Microplastic Pollution Load Index (MPLI). **Results:** All samples contained MPs. Formula-type CIFs averaged 686 ± 308 MPs/100 g, while puree-type CIFs contained markedly higher levels, ranging from 480 to 20,140 MPs/100 g. Fragments were the dominant morphology (66% in formula; 49.3% in puree), and black particles were most prevalent (36.1% in formula; 25% in puree). The estimated daily intake (EDI) was 432 ± 257 MPs/day for formula-fed infants and a median of 1,709 MPs/day (IQR: 5,201) for puree-fed infants. MPCF classified formula samples as significantly to extremely contaminated, whereas most puree samples fell into the extreme category. MPLI indicated minimal risk for formula but ranged from minimal to extremely high for puree-type CIFs. **Conclusion:** This study provides the first evidence of MPs in Malaysian CIFs, with puree products showing greater contamination and risk. Findings underscore the need for stricter monitoring, safer packaging, and further research on the long-term health impacts of infant MP exposure.
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Corresponding Author:
Yu Bin Ho, PhD
Email: yubin@upm.edu.my

INTRODUCTION

Infancy is a critical period of rapid physical and cognitive development, where exposure to environmental toxicants can result in persistent changes in structure and function, with potential long-term effects on health (1). Infants have immature metabolic pathways, making them less efficient in removing harmful substances from their bodies. Due to their smaller size, they experience a higher body burden of chemical exposure, rendering them more vulnerable to toxic effects (1). Furthermore, infants consume more food, water, and air per unit of body weight than adults, increasing their absorption of environmental contaminants (2). This makes them particularly susceptible to the harmful impacts of microplastics (MPs), which are pervasive pollutants that persist in the environment and accumulate in human bodies (3-4).

Microplastics, smaller than 5 mm, originate from both the degradation of larger plastics and intentional production for consumer products (5). These particles have been detected in various human tissues, including breast milk, blood, and even the placenta, highlighting the potential health risks associated with their exposure (3-4). Recent studies have identified MPs in both formula-type and puree-type CIFs, posing concerns for infants who are exclusively fed these products. Research has shown that formula-type CIFs contain microplastics, with an average of 42 ± 27 particles per 100g, with infants consuming approximately 49 ± 32 particles daily (2). While microplastics have been reported in various food products, information on their occurrence in puree-type commercial infant foods remains limited (6). The primary sources of MPs in these foods are believed to be plastic packaging materials, such as polypropylene, which degrade over time (7).

Puree- and formula-type CIFs are considered high-risk matrices for microplastic contamination because several mechanisms can contribute to particle release. Thermal processes used during manufacturing or preparation—

such as sterilization, heating, and mixing—can accelerate polymer degradation and increase microplastic shedding from food-contact plastics (8). Likewise, pouch-type packaging and multilayer plastic film may release particles through wear, tearing, and routine handling (9). Despite these recognized pathways, global regulations remain limited: Codex Alimentarius (10) has not established microplastic limits for food, and both European Food Safety Authority (EFSA) (11) and World Health Organization (WHO) (12) report insufficient toxicological and exposure data to derive health-based guidance values. Malaysia likewise has no specific standards, permissible limits, or routine monitoring requirements for microplastics in infant foods under the Food Act 1983 and Food Regulations 1985, underscoring the need for empirical data to inform future policymaking.

The presence of MPs in infant foods is especially concerning due to infants' heightened sensitivity to environmental contaminants. Their developing organs and systems, including neurobehavioral, immunological, and metabolic pathways, make them more vulnerable to the harmful effects of MPs (2, 13). Exposure to MPs may cause oxidative stress, inflammation, and disruptions to the immune system, with potential long-term health implications such as developmental delays, carcinogenesis, and metabolic disorders (3). This study aims to assess the occurrence of MPs in formula-type and puree-type CIFs in Malaysia, focusing on their abundance, size, shape, and color. Additionally, it seeks to estimate the daily intake of MPs and evaluate the potential health risks posed to infants who consume these products.

MATERIALS AND METHODS

Sampling of Commercial Infant Food (CIF)

A total of 42 commercial infant food (CIF) samples were collected, comprising 21 formula-type and 21 puree-type products, with three replicates per brand. The brands were selected based on a survey of 413 parents with infants aged 6–24 months in the Klang Valley, which identified the most commonly consumed CIF brands in Malaysia. This survey originated from a Master's dissertation (14), which identified the commonly consumed CIF brands in Malaysia. This approach ensured representation of products frequently purchased and used by local consumers. Although proportional selection based on national market share was not feasible due to the lack of publicly available sales data, the sample set reflects widely consumed brands across diverse packaging types (box, can, pouch, bottle) and manufacturing origins. This sampling framework provides a representative overview of CIF products available to Malaysian parents. Samples were obtained from local supermarkets, grocery stores, and online platforms, and originated from multiple manufacturing regions, including Europe, the USA, New Zealand, and Malaysia (**Table I**).

Table I: Product Information on CIFs

Types of CIF	Samples	Country/ Region of Origin	Weight (g)	Expiry Date	Packaging Type
Formula-type	F1	Thailand	300	14/09/2025	Box
	F2	Netherlands	400	31/12/2025	Can
	F3	Netherlands	400	08/02/2026	Can
	F4	Thailand	350	22/11/2025	Can
	F5	Germany	400	13/09/2026	Can
	F6	Spain	360	23/01/2026	Can
	F7	Singapore	200	04/03/2026	Box
Puree-type	P1	Europe	100	16/12/2024	Pouch
	P2	Europe	90	05/01/2025	Pouch
	P3	Australia	120	13/01/2025	Pouch
	P4	USA	128	25/03/2025	Pouch
	P5	New Zealand	120	15/12/2024	Pouch
	P6	Malaysia	75	23/06/2025	Bottle
	P7	Malaysia	50	14/05/2025	Bottle

Materials and Chemicals

Ultrapure water was obtained from a Millipore Milli-Q system. Digestion of samples was performed using 30% hydrogen peroxide (H_2O_2) (R&M Chemicals, Malaysia). Filtration was conducted sequentially through cellulose filters (Whatman Grade 4, 25 µm; Whatman Grade 1, 11 µm; Cytiva, China) and mixed cellulose ester (MCE) filters (0.8 µm; Bioflow, Malaysia). All glassware was acid-washed with 69% nitric acid (HNO_3) and rinsed with ultrapure water to prevent cross-contamination.

Analysis of Microplastics in Formula-Type CIF

The analysis of microplastics (MPs) in CIF followed the protocol described by Kadac-Czapska et al. (2). For each test, 10 g of the CIF sample was weighed and transferred into a glass conical flask. The samples were mixed with 70 mL of ultrapure water preheated to 60 °C, followed by the addition of 50 mL of 30% H_2O_2 to initiate digestion. The flasks were covered with watch glasses and incubated in a water bath at 60 °C until coagulation occurred (≈8 h). The digested material was then pre-sieved through a 200 µm stainless-steel sieve and subsequently filtered under reduced pressure using cellulose filters (25 µm and 11 µm, Cytiva, China) and mixed cellulose ester (MCE) filters (0.8 µm, Bioflow, Malaysia).

Recovery of the Digestion Method

To evaluate the effectiveness of the digestion method and its impact on MPs, a recovery experiment was conducted by spiking selected formula-type CIF samples with known quantities of polypropylene (PP), polyethylene terephthalate (PET), and polyamide (PA). The mixtures were processed according to the procedure described previous section. Microplastic standards (Center for Marine Debris Research, USA) were used, and each polymer was tested in triplicate. The recovery (R) was calculated using the following equation, as described by Kadac-Czapska et al. (2):

$$R = \frac{m_3 - m_2}{m_1} \times 100\% \quad (1)$$

where m1 is the weight of MPs introduced into the sample (g), m2 is the weight of the filter paper (g), and m3 is the combined weight of the dried filter paper and MPs retained on it (g).

Identification and Characterization of Microplastics

Identification of microplastics in formula- and puree-type CIF samples was carried out using an Olympus CX23 compound microscope (Japan). Filter papers were divided into four quadrants, and each section was carefully screened to ensure comprehensive detection. Images obtained from the microscope were subsequently analyzed, and particles were classified as microplastics based on their morphological features, including size, shape, and color.

Quality Control

Throughout sampling, preparation, and analysis, contact with plastic materials was strictly avoided by using only glassware in laboratory procedures (15). All glassware was pre-cleaned with ultrapure water and nitric acid, then stored in closed cabinets to minimize airborne contamination (16). A Milli-Q ultrapure water blank was included as a control to monitor potential self-contamination during laboratory processing. During all handling steps, personnel wore cotton laboratory coats and nitrile gloves to reduce external contamination (17).

Assessment of Estimated Daily Intake (EDI)

The estimated daily intake (EDI) of microplastics was calculated according to the formula described by Kadac-Czapska et al. (2):

$$EDI = \frac{C \times IR}{100} \quad (2)$$

where C represents the microplastic abundance (MPs/100 g) and IR is the daily consumption of CIF by infants. Data on daily consumption were obtained from a survey in a master's dissertation by Elfikrie (14), the same survey used to identify commonly consumed CIF brands in Malaysia.

The EDI assessment in this study focuses on infants aged 6–24 months, as this age group corresponds to the complementary feeding period, during which infants are progressively introduced to solid and semi-solid foods while continuing breastfeeding up to 24 months. This is in accordance with the World Health Organization (WHO) recommendation that infants should be exclusively breastfed for the first 6 months of life and subsequently offered appropriate complementary foods alongside continued breastfeeding up to 24 months and beyond (18-19). Accordingly, the EDI values estimated for puree-type commercial infant foods represent complementary feeding exposure rather than exclusive dietary intake. Feeding practices vary depending on infant age, breastfeeding status, cultural norms, and caregiver preference; therefore, variability in consumption introduces uncertainty into the exposure assessment and should be considered when interpreting the EDI and associated risk characterization.

Risk Characterization

The Microplastic Contamination Factor (MPCF) was calculated to assess the extent of microplastic contamination in CIFs relative to background levels, while the Microplastic Pollution Load Index (MPLI) was applied to determine the degree of contamination and facilitate comparisons across samples. These indices were calculated using equations (3) and (4), as described by Altunışık (20).

MPCF = MPi/ MPb (3)

MPLI = (MPCF1 x MPCF2 x …..MPCFx)1/x (4)

where MPi is the quantity of MPs in the sample i; x is the total number of samples and MPb is the background concentration of MPs. In this study, the lowest MP abundance of 130 particles/100 g for formula and 120 particles/100 g for puree were chosen as the background concentration (MPb). The risk categories for MPCF and MPLI were adopted from Ibeto et al. (21). **Table II** summarizes the contamination-level criteria for MPCF and the risk-level criteria for MPLI.

Table II: Contamination-level criteria for MPCF and Risk-level criteria for MPLI adopted from Ibeto et al. (21)

Microplastic Contamination Risk Factor (MPCF)	
Contamination Level	**MPCF Value**
Minimum	<1
Moderate	1-3
Significantly polluted	3-6
Extremely polluted	>6
Microplastic Pollution Load Index (MPLI)	
Risk Level	**MPLI Value**
Low	<10
Moderate	10-20
High	20-30
Extremely High	>30

RESULTS

Recovery of the Digestion Method

The efficiency of the digestion method for isolating MPs from CIFs was tested through recovery experiments with spiked standard MPs. The overall recovery rate averaged 70.49% ± 13.6, indicating acceptable recovery performance, with the highest recovery observed for PA6 (97.22% ± 9.4), followed by PET (61.54% ± 10.78) and

PP (52.7% ± 17.3). The lower recovery observed for PET and PP is unlikely to be caused by chemical degradation during hydrogen peroxide digestion, as both polymers are generally resistant to H_2O_2 treatment and only minor discoloration of PET has been reported (22). Instead, physical processes during digestion, including foam-related particle loss and losses during handling and filtration (22), likely account for the reduced recovery. Consequently, PET- and PP-associated microplastic abundance in the present study may be underestimated.

Occurrence of Microplastics in Formula-Type and Puree-Type CIFs

Analysis confirmed the presence of microplastics in all 14 CIF brands (**Table III**). Normality of microplastic occurrence data was assessed using the Shapiro–Wilk test. Data from formula-type CIFs were normally distributed ($p > 0.05$) and are therefore presented as mean ± SD, whereas puree-type CIFs were not normally distributed ($p < 0.05$) and are reported as median with interquartile range (IQR). Formula-type CIFs showed relatively consistent levels of contamination, averaging 686 ± 308 MPs/100 g, with the highest values recorded for Brands F4 (973 ± 142 MPs/100 g) and F5 (970 ± 80 MPs/100 g). By comparison, puree-type CIFs displayed much greater variability, with microplastic concentrations ranging from 480 (120–1070) MPs/100 g in Brand P1 to 20,140 (18,340–24,070) MPs/100 g in Brand P7. These findings demonstrate that while both product types contain MPs, puree-type CIFs are subject to markedly higher and more variable contamination levels.

Microplastic Characteristics in Formula-Type CIF

Shape

Morphological analysis identified six types of microplastics in CIFs: fiber, fragment, film, pellet, granular, and irregular. As shown in **Fig. 1**, fragments were the dominant morphology in both product types, accounting for 66.0% of particles in formula-type and 49.3% in puree-type CIFs. Notable differences were observed in the distribution of other shapes. In formula-type products, films represented 17.5%, followed by fibers (6.9%), irregulars (5.3%), and granules (4.3%). In contrast, puree-type products contained higher proportions of fibers (23.4%), pellets (14.6%), and films (12.7%), while irregular and granular particles were absent. Pellets occurred exclusively in puree-type CIFs and were not detected in formula-type samples. These findings highlight distinct differences in microplastic shape distribution between formula- and puree-based infant foods.

Color

Microplastics in both formula- and puree-type CIFs exhibited a wide range of colors, with black being the predominant color, followed by red, transparent, and yellow, while other colors appeared in smaller proportions (**Fig. 1** and **2**). In formula-type CIFs, black particles accounted for 36.1%, followed by red (18.8%), transparent (17.0%), and yellow (11.8%). Minor colors included blue (7.6%), white (4.4%), brown (2.8%), green (1.0%), and pink (0.4%). Similarly, puree-type CIFs were dominated by black (25.0%), red (20.0%), transparent

Table III: Occurrence (particles/100 g) and Estimated Daily Intake (particles/day) of Microplastics in Commercial Infant Foods

Samples	n	Formula-type Occurrence (Mean ± SD)	Puree-type Occurrence (Median, IQR)	Formula-type EDI (Mean ± SD)	Puree-type EDI (Median, IQR)	Min[a]	Max[a]
Formula-type CIF							
All samples	21	686 ± 308	–	432 ± 257	–	130 / 56	1100 / 862
Brand							
F1	3	567 ± 435	–	245 ± 188	–	130 / 56	1000 / 433
F2	3	423 ± 307	–	275 ± 198	–	230 / 148	780 / 503
F3	3	503 ± 264	–	303 ± 159	–	270 / 162	790 / 475
F4	3	973 ± 142	–	670 ± 98	–	820 / 565	1100 / 756
F5	3	970 ± 80	–	796 ± 66	–	890 / 731	1050 / 862
F6	3	860 ± 180	–	568 ± 119	–	660 / 436	1010 / 668
F7	3	500 ± 151	–	167 ± 50	–	340 / 113	640 / 213
Puree-type CIF							
All samples	21	–	3830 (2190)	–	1709 (5201)	120 / 87	4810 / 10710
Brand							
P1	3	–	480 (950)	–	341 (689)	120 / 87	1070 / 776
P2	3	–	4500 (890)	–	3222 (638)	3910 / 2806	4810 / 3444
P3	3	–	2590 (2190)	–	1709 (1446)	2290 / 1511	4480 / 2957
P4	3	–	6410 (7840)	–	5423 (6632)	4820 / 4078	12660 / 10710
P5	3	–	3830 (3970)	–	509 (3821)	3630 / 257	7600 / 4078
P6	3	–	2120 (1590)	–	1908 (1431)	1980 / 1782	3570 / 3213
P7	3	–	20140 (5730)	–	1490 (435)	18340 / 1357	24070 / 1782

[a] Min and Max values are presented as Occurrence / Estimated Daily Intake (EDI).
n = number of samples; SD = standard deviation; IQR = interquartile range

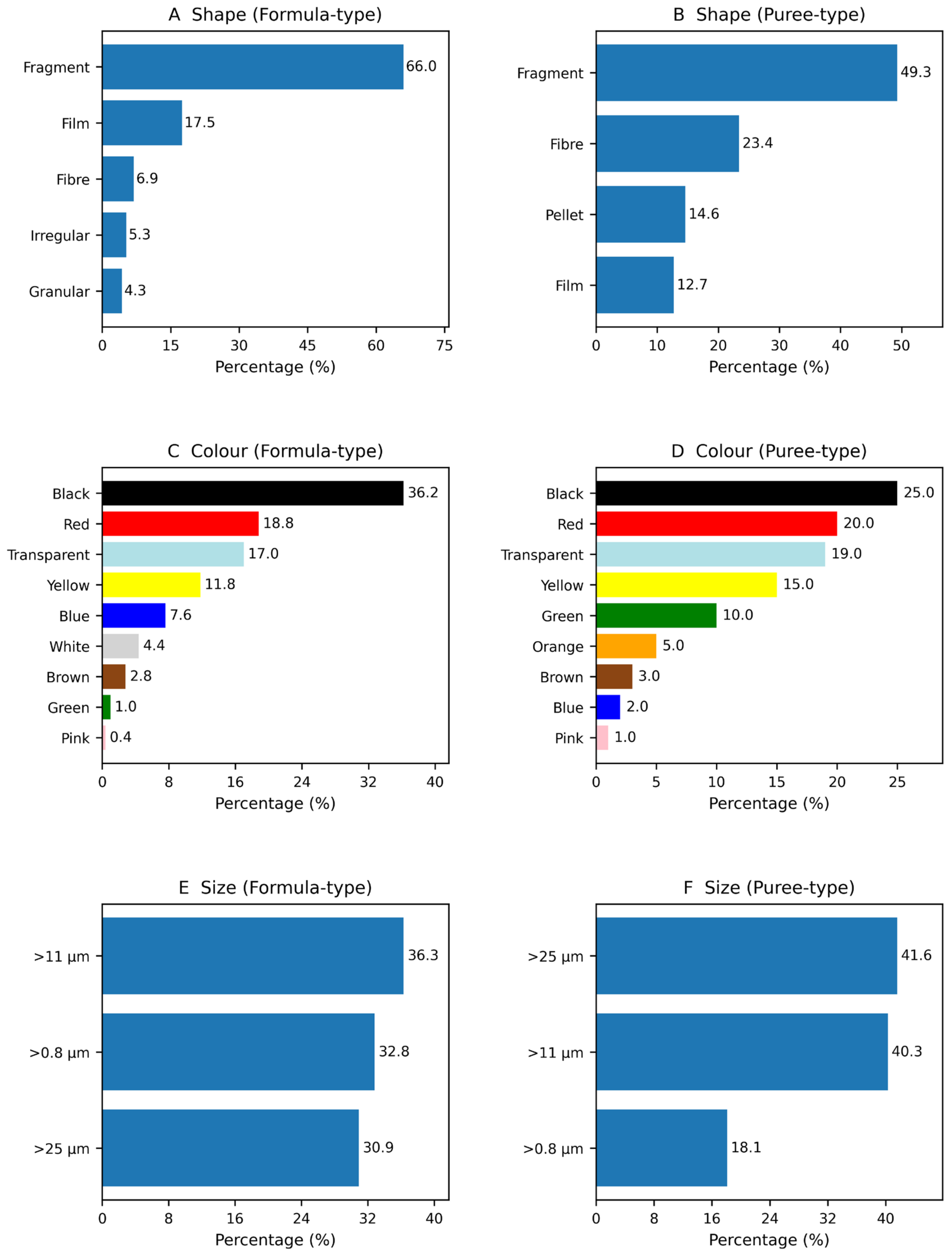

Fig. 1: Microplastic characteristics in commercial infant food samples, showing distribution of particle shapes (A–B), colours (C–D), and sizes (E–F).

(19.0%), and yellow (15.0%), with smaller contributions from green (10.0%), orange (5.0%), brown (3.0%), blue (2.0%), and pink (1.0%). While both product types shared similar dominant colors, formula-type samples displayed a slightly broader spectrum, particularly with the presence of white and higher proportions of blue and brown particles.

Size

Microplastic size distribution was assessed using filters with pore diameters of 25 µm, 11 µm, and 0.8 µm. As shown in **Fig. 1**, particles in the 11–24 µm size range were the most prevalent, representing 36.3% of total MPs in formula-type and 40.3% in puree-type CIFs. Larger particles (>25 µm) were more abundant in puree-type samples (41.5%) compared to formula-type (30.9%). In contrast, smaller particles (0.8–10 µm) were more common in formula-type CIFs (32.8%) than in puree-type products (18.1%).

Estimated Daily Intake (EDI) of Microplastics by Infants

The estimated daily intake (EDI) of MPs from CIFs varied between formula-type and puree-type products (**Table III**). For formula-type CIFs, the average intake was 432

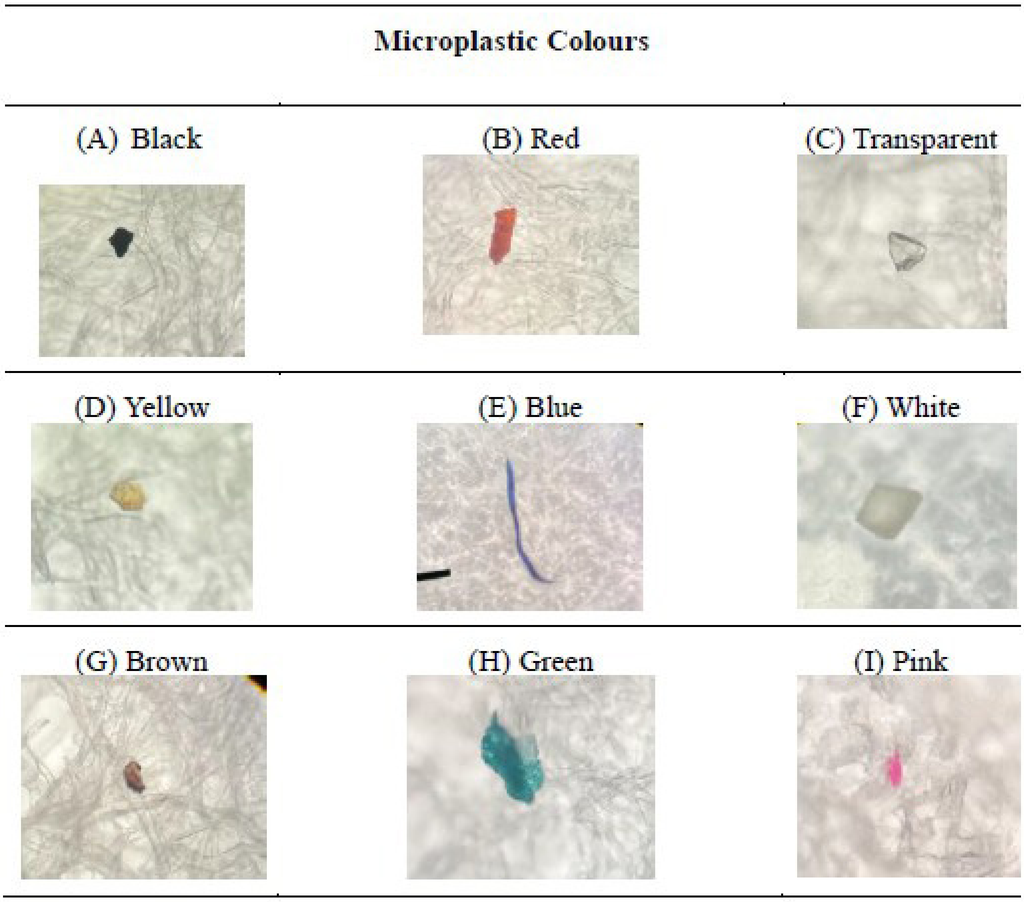

Fig. 2: Representative microscopic images showing the variety of microplastic colours identified in commercial infant food (CIF) samples. Panels represent different colour categories: (A) Black, (B) Red, (C) Transparent, (D) Yellow, (E) Blue, (F) White, (G) Brown, (H) Green, and (I) Pink.

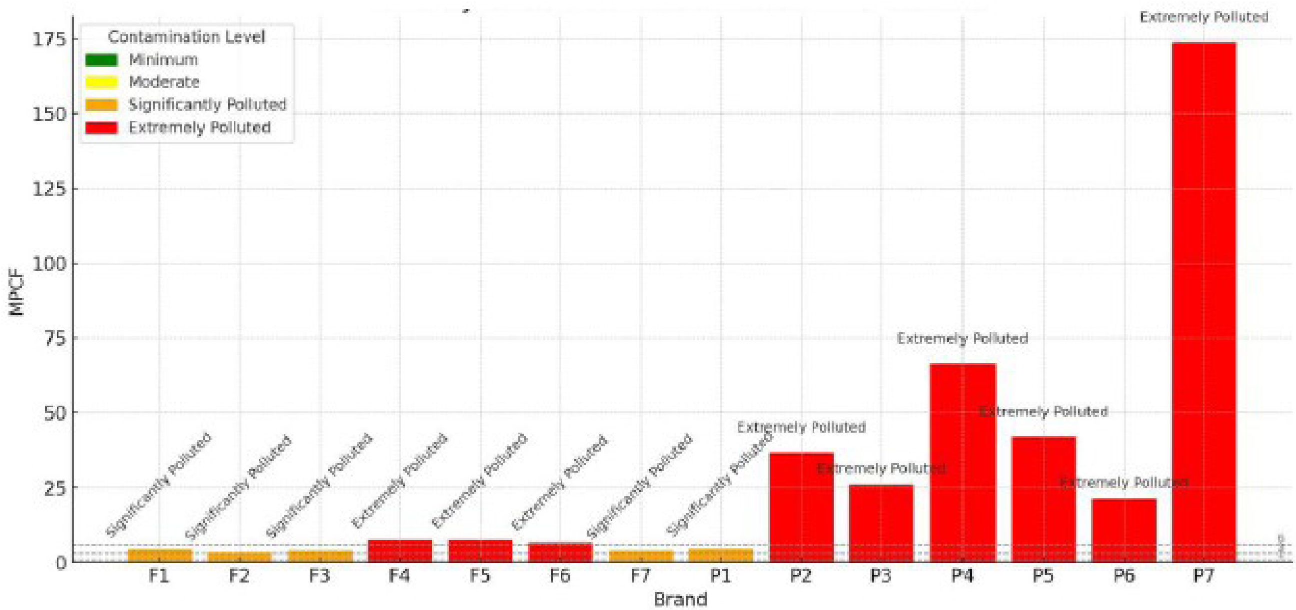

Fig. 3: Microplastic Contamination Factor (MPCF) by brand of commercial infant food (CIF). Bars are color-coded by contamination level: minimum (<1), moderate (1–3), significantly polluted (3–6), and extremely polluted (>6).

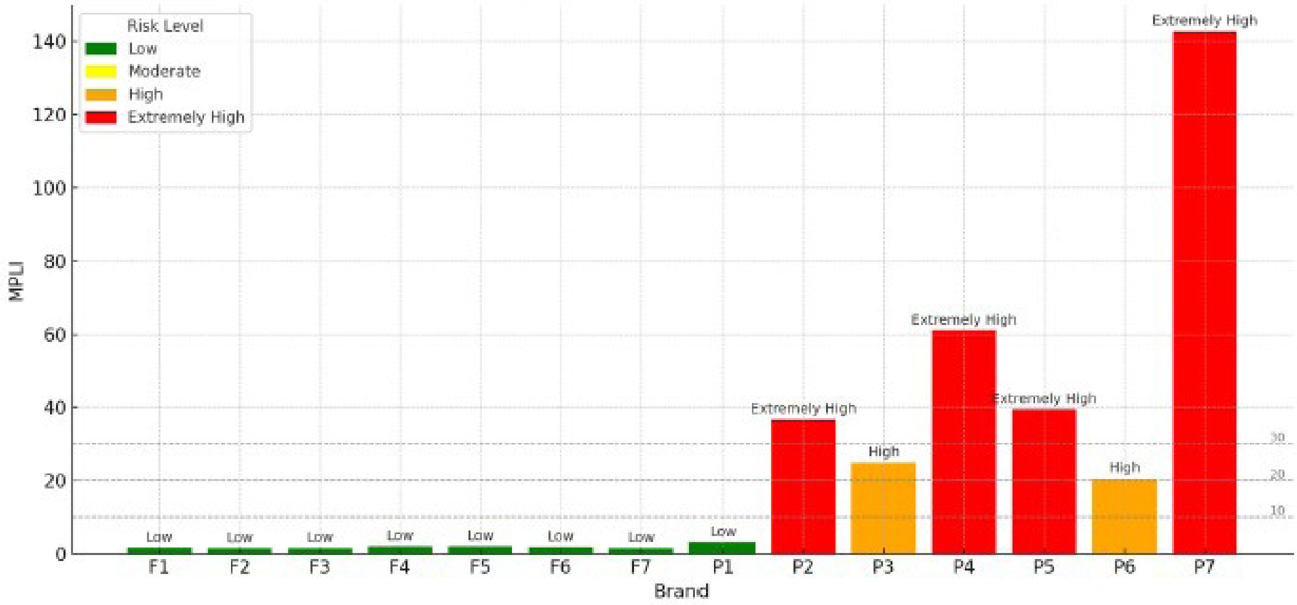

Fig. 4: Microplastic Pollution Load Index (MPLI) by brand of commercial infant food (CIF). Bars are color-coded to represent risk levels: low (<10), moderate (10–20), high (20–30), and extremely high (>30).

± 257 MPs/day, with Brand F5 showing the highest exposure (796 ± 66 MPs/day) and Brand F7 the lowest (167 ± 50 MPs/day). In comparison, puree-type CIFs showed markedly higher and more variable intakes, with a median of 1,709 MPs/day (IQR: 5,201). Across brands, the lowest median intake was observed in P1 (341 MPs/day, IQR: 689), while the highest occurred in P4 (5,423 MPs/day, IQR: 6,632). The minimum daily intake for puree-type products was 87 MPs/day (P1), while the maximum reached 10,710 MPs/day (P4). These findings indicate that although formula-type products contributed relatively stable exposures, puree-type CIFs posed substantially greater and more variable intake risks.

Risk Characterization

Fig. 3 and **4** illustrate the extent of microplastic contamination in CIFs, assessed using the Microplastic Contamination Factor (MPCF) and the Microplastic Pollution Load Index (MPLI). For formula-type CIFs, MPCF values ranged from 3.0 to 7.5. Four brands (F1, F2, F3, and F7) were classified as significantly polluted (MPCF = 3–6), while three brands (F4, F5, and F6) were categorized as extremely polluted (MPCF > 6). In contrast, the MPLI values for all formula-type brands fell between 1.0 and 2.0, indicating a consistently low risk level (MPLI < 10).

For puree-type CIFs, contamination was considerably higher and more variable. MPCF values ranged from 4.59 in P1 to 173.75 in P7. Except for P1, which was significantly polluted, all other puree-type brands were categorized as extremely polluted. Correspondingly, MPLI values revealed a broader risk distribution: P1 was low risk, P3 and P6 were high risk, while P2, P4, P5, and P7 were classified as extremely high risk.

Overall, these indices highlight a clear distinction between product types: formula-type CIFs showed relatively controlled contamination with minimal risk, whereas puree-type CIFs exhibited higher contamination levels.

DISCUSSION

Occurrence of Microplastics in Formula-Type and Puree-Type CIFs

As shown in **Table III**, MPs were detected in all formula-type and puree-type CIFs. Formula samples contained an average of 686 ± 308 MPs/100 g, with the highest levels in F4 (973 ± 142 MPs/100 g) and F5 (970 ± 80 MPs/100 g), both of which were packaged in cans. The elevated contamination in canned products may be linked to packaging materials; boxed milk powder inner layers (plastic-aluminum foil laminate) were shown to contribute more microplastics than canned counterparts. Furthermore, feeding bottles significantly increased MP exposure during formula preparation (23). In contrast, boxed products in this study (F1: 567 ± 435 MPs/100 g; F7: 500 ± 151 MPs/100 g) showed lower contamination than canned samples, which differs from Zhang et al. (23), who reported generally lower MP levels overall, with boxed milk powder (7 ± 3 items/100 g) slightly more contaminated than canned milk powder (4 ± 3 items/100 g).

For puree-type CIFs, MPs were detected at markedly higher concentrations, with medians ranging from 480 (IQR 950) MPs/100 g in P1 to 20,140 (IQR 5,730) MPs/100 g in P7. Since no previous studies have reported MPs in puree-type CIF, these values were compared against other known dietary exposure sources. The concentrations observed here far exceed those typically reported in bottled water (5–100 particles/L) (24-25) and are comparable to or even higher than those found in seafood and salt, which are recognized as major dietary sources of MPs (26-27). These findings underscore puree-type CIFs as a potentially significant route of infant exposure to MPs, raising concerns given the heightened vulnerability of this population group.

Microplastic Characteristics in Formula-type Commercial Infant Food

Shape and Color

Granular, fiber, film, pellet, fragment, and irregular particles were identified across all formula-type and puree-type CIF samples. Fragments dominated the morphological distribution, representing 66.0% in formula-type and 49.3% in puree-type samples, followed by films and fibers (**Fig. 1**). These results are consistent with the findings of Kadac-Czapska et al. (2), who also reported fragment, film, and fiber as the predominant MPs in formula-type CIFs. Similarly, Zhang et al. (23) observed that fragmented MPs were the most common morphology in both canned (77%) and boxed (72%) milk powder.

The dominance of fragments highlights packaging as a major source of contamination. Fragments often result from the mechanical or thermal breakdown of rigid plastics such as polyethylene (PE) and polypropylene (PP), which are widely used in packaging, seals, and linings (28). Additional contributions may arise from the plastic spoons often included in powdered formula. Fibers were also frequently detected, raising concern given their higher toxicity potential; Gray and Weinstein (29) reported that fibers are more hazardous than other morphologies due to their ability to tangle, obstruct, and damage tissues, as well as persist longer within organisms. This is particularly worrisome for infants, whose immune systems are still developing.

In terms of color, ten categories were identified: black, red, white, transparent, yellow, blue, brown, orange, green, and pink (**Fig. 1**). Black MPs were dominant in both formula-type (36.1%) and puree-type (25.0%) samples, in line with findings from Kadac-Czapska et al. (2) in formula milk and Basaran et al. (15) in honey. Their prevalence likely reflects contamination from manufacturing processes, packaging, and airborne deposition (30). Sobhani et al. (31) further highlighted that scissoring, tearing, or twisting packaging can release MPs directly into food. Other colors (red, blue, yellow, brown, and pink) were also detected, potentially originating from colored plastic spoons provided with CIFs (32).

Size

The size of microplastics (MPs) is a critical determinant of their fate, bioaccumulation, and potential health risks in humans (33). Kadac-Czapska et al. (6) noted that smaller MPs are more easily ingested, particularly by infants, as they can mix with food or liquids without being visibly detected. Moreover, particle size influences gastrointestinal retention: smaller MPs are more likely to adhere to the intestinal lining or become trapped within gut folds, thereby prolonging residence time and increasing opportunities for interaction with internal tissues (6). In this study, MPs within the 11-24 µm range were the most common, accounting for 36.3% in formula-type and 40.3% in puree-type CIFs (**Fig. 1**). Larger particles (>25 µm) were more abundant in puree-type samples (41.5%) than formula-type (30.9%), while the smallest size fraction (0.8–10 µm) was more prevalent in formula-type (32.8%) compared with puree-type (18.1%).

The detection of such small MPs raises substantial health concerns. Bhavsar et al. (34) highlighted that MPs smaller than 50 µm may cross the intestinal barrier and translocate to secondary organs. Indeed, MPs of comparable size have recently been identified in human biological samples, including placenta (35), liver tissue (4–30 µm) (36), arteries (37), and faeces (50–500 µm) (38). For infants, whose gastrointestinal and immune systems are not fully developed, ingestion of such particles may be especially hazardous. Translocation of MPs during early life stages could impair organ function, trigger inflammatory responses, and interfere with nutrient uptake, posing long-term health implications.

Estimated Daily Intake (EDI) of Microplastics by Infants

Assessing infant exposure to MPs via ingestion is critical, as it represents the dominant pathway of human intake. MPs have been detected in numerous food products, including seaweed (33), honey (15), salt (39), rice (34), and bottled water (16), confirming their widespread presence in the food chain. In this study (**Table III**), the estimated daily intake (EDI) of MPs for infants consuming formula-type CIFs averaged 432 ± 257 MPs/day, with values ranging from 56 MPs/day (Brand F1) to 862 MPs/day (Brand F5). In contrast, puree-type CIFs exhibited significantly higher and more variable EDIs, with a median of 1,709 MPs/day (IQR 5,201) and brand-specific values ranging from 341 MPs/day (P1) to 5,423 MPs/day (P4), with maximum levels reaching 10,710 MPs/day.

MP exposures have been linked to gastrointestinal inflammation, oxidative stress, and immune system disruption. MPs have been shown to damage gut integrity and alter the microbiome in animal studies (40), while also inducing oxidative stress, lipid peroxidation, DNA damage, and activation of cell stress pathways in cellular models (41). Additionally, MPs can trigger immune dysregulation by interfering with intracellular signaling and inflammatory pathways (42). Considering that infants possess immature immune and gastrointestinal systems, these findings are particularly relevant for this vulnerable group."

Beyond MPs directly ingested from CIFs, other pathways can further elevate exposure. Formula preparation using plastic bottles has been shown to release 65 ± 18 MPs/L (23), while puree-fed infants may face additional contamination from packaging, utensils, and storage. Environmental sources such as airborne MPs (43) and synthetic fibres from infant clothing (44) also contribute to background intake. As infants grow and transition to solid foods, particularly rice-based products such as biscuits, porridges, and rice purees, their exposure burden is expected to increase further (34). These findings underscore the need for further investigation into cumulative MP exposure in infants, particularly concerning long-term health risks and potential regulatory measures to mitigate contamination in infant food products.

Risk Characterization

Microplastic Contamination Factor (MPCF) and Microplastic Load Index (MPLI)

The contamination assessment based on the Microplastic Contamination Factor (MPCF) and Microplastic Pollution Load Index (MPLI) revealed distinct patterns between formula-type and puree-type CIFs (**Fig. 3** and **4**). For formula-type CIFs, MPCF values ranged between 3.0 and 7.5. Brands F1, F2, F3, and F7 were classified as significantly polluted (MPCF = 3–6), while Brands F4, F5, and F6 fell into the extremely polluted category (MPCF > 6). Despite these contamination levels, the MPLI values across all formula-type samples were consistently low (1.0–2.0), corresponding to low risk. This aligns with previous findings where measurable MP loads did not necessarily translate into elevated risk levels. For instance, Ibeto et al. (21) reported MPLI values of 1.71 for bottled water, while Basaran et al. (45) documented 2.80 for milk.

In contrast, puree-type CIFs demonstrated greater variability and higher contamination burdens. MPCF values spanned from 4.59 in P1 (significantly polluted) to 173.75 in P7 (extremely polluted), with samples P2, P3, P4, P5, and P6 also classified as extremely polluted. Correspondingly, MPLI values revealed risk differences, where P2, P4, P5, and P7 were categorized as extremely high risk, while P3 and P6 were classified as high risk. Only P1 showed low risk, consistent with its lower MPCF value. Compared with formula-type CIFs, puree-type products contribute disproportionately to infant MP exposure, with contamination and risk levels far exceeding those previously reported for other food categories such as bottled water (1.71) and milk (2.80) (21, 45).

Overall, while formula-type CIFs in this study exhibited relatively low MPLI values comparable to other low-risk foods, puree-type CIFs displayed markedly higher MPLI values (3.13–142.6), highlighting their significance as a major source of infant MP exposure. Although formula-type CIFs may pose a lower contamination risk, the susceptibility of infants due to their higher intake of food per body weight and underdeveloped physiological systems, even to low-level exposures, should not be overlooked.

CONCLUSION

This study confirms the widespread presence of MPs in both formula-type and puree-type CIFs, with notable differences in concentration and risk levels between product types. While fragments and black-colored MPs dominated, puree-type CIFs exhibited substantially higher contamination and risk compared to formula-type products. These findings underscore the urgent need for stricter monitoring, regulatory standards, and further research to evaluate the long-term health impacts of MPs on infants. However, the study is limited by a relatively small sample size, possible contamination during handling, and the exclusion of nanoscale MPs, and the fact that the polymer composition of food packaging materials was not analyzed; therefore, conclusions regarding specific packaging materials as sources of microplastics could not be established, highlighting the need for broader and more advanced investigations.

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