ORIGINAL RESEARCH

doi 10.63923/smhs.2026.132

Summa Medical and Health Sciences
2026; v. 2: e132

What's in Our Drinks? First Comparison of Anthropogenic Microparticles Contamination in Industrialized Beverages in Brazil

O que está nas nossas bebidas? Primeira comparação da contaminação por micropartículas antropogênicas em bebidas industrializadas no Brasil

Stanley Lohan Nichel Alves*[1], Ana Luísa Marinato Aguiar Alves[2], Beatriz Fava Souza de Assis[2]
Júlia Lima dos Santos[2], Gustavo Martins Rocha[1], Fabian Sá[1]

Abstract

Currently, the presence of anthropogenic microparticles (AMPs) in products intended for human consumption has been increasingly reported in science literature. However the presence of these pollutants in industrialized beverages has not yet been evaluated in many countries. The present study focused on the abundance of AMPs in beverages consumed in Brazil: mineral water, soda, juice (pure and not pure), milk and beer. AMPs were found in all samples analyzed, with average of 101.89 ± 161.34 AMPs/L. The highest average concentration of AMPs was detected in fruit juice, packaged in carton (547.7 ± 427.7 AMPs/L), while the lowest was found in pure fruit juice, packaged in PET bottles (average of 9.1 ± 9.4 AMPs/L). Juice represents the main source of exposure for Brazilian population by the estimated daily intake, followed by water and soda, highlighting a continuous human exposure to these contaminants. This study provides a valuable basis for future assessments of the potential health risks associated with human exposure to AMPs and for the development of public policies aimed at reducing their concentrations in products intended for human consumption.

KEYWORDS: Food safety; Pollution; Ingestion hazard; Anthropogenic microparticles.

[1]Universidade Federal do Espírito Santo (UFES), Departamento de Oceanografia e Ecologia, Vitória, ES, Brazil. [2]Escola São Domingos, Vitória, ES, Brazil.
*Correspondence: stanlohan@gmail.com

Resumo

Atualmente, a presença de micropartículas antropogênicas (MPAs) em produtos destinados ao consumo humano tem sido cada vez mais relatada na literatura científica. Contudo, em muitos países a presença desses poluentes em bebidas industrializadas ainda não foi avaliada. O presente estudo focou na abundância de MPAs em bebidas consumidas no Brasil: água mineral, refrigerante, suco (integral e não integral), leite e cerveja. MPAs foram encontradas em todas as amostras analisadas, com média de 101.89 ± 161.34 MPAs/L. A maior concentração média de MPAs foi detectada em suco de fruta envasado em embalagem cartonada (547.7 ± 427.7 MPAs/L), enquanto a menor foi encontrada em suco de fruta integral, envasado em garrafas PET (média de 9.1 ± 9.4 MPAs/L). O suco representa a principal fonte de exposição para a população brasileira, de acordo com a ingestão diária estimada, seguido por água e refrigerante, evidenciando uma exposição humana contínua desses contaminantes. Este estudo fornece uma base valiosa para futuras avaliações dos potenciais riscos à saúde associados à exposição humana às MPAs e para elaboração de políticas públicas voltadas para a redução de suas concentrações em produtos destinados ao consumo humano.

PALAVRAS-CHAVE: Segurança alimentar; Poluição; Risco de ingestão; Micropartículas antropogênicas.

1. Introduction

The production and consumption of polymeric materials and other synthetic compounds have grown exponentially in recent decades (Napper & Thompson, 2020), driven by the increasing demand for plastic polymers, which resulted in a production of approximately 414 million metric tons of these materials in 2023 (Plastics Europe, 2024). This proliferation, coupled with inefficient management and disposal systems, emerge as one of the main environmental and public health concerns (Amato-Lourenço et al., 2020; Lee et al., 2024).

Synthetic or semi-synthetic materials often incorporate chemical additives to meet specific commercial purposes, such as bisphenol A, phthalates, and flame retardants (Teuten et al., 2009; Campanele et al., 2020), which may pose risks to human health when released from the matrix, absorbed by organisms, and transferred along food chains through bioaccumulation and biomagnification (Kumar et al., 2022). Furthermore, particles derived from these materials can interact with hazardous contaminants such as heavy metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, organochlorine pesticides, and pharmaceuticals (De-La-Torre, 2020; Tang et al., 2020; Vasudeva et al., 2025), which are associated with clinical alterations in liver function, insulin resistance, reproductive and neurological disorders, as well as endocrine and cardiovascular dysfunctions (Karbalaei et al., 2018; Campanele et al., 2020; Senathirajah et al., 2021).

Within this context, anthropogenic microparticles (AMPs), including microplastics (MPs), synthetic and semi-synthetic fibers, cellulose-based regenerated fibers, paint particles, and other anthropogenic debris smaller than 5 mm, have attracted considerable scientific attention due to their widespread distribution and potential environmental and human health impacts (Andrady, 2017; Athey & Erdle, 2022; Finnegan et al., 2022). Among these particles, MPs are recognized for their high adsorption capacity, and potential to transport and release toxic contaminants into the environment (Karbalaei et al., 2018; Kim et al., 2021). These microparticles may be intentionally manufactured at sizes below 5 mm or result from the degradation of larger items, such as household utensils, fishing nets, and even the washing of textiles (Browne et al., 2011; Andrady, 2017; Fu & Wang, 2019). As a consequence, they are widely distributed in both aquatic and terrestrial environments, being incorporated into biota (Fu & Wang, 2019; Napper & Thompson, 2020; Wang et al., 2021) and transferred along food webs through predator–prey interactions (Le Guen et al., 2020). This process ultimately leads to increasingly frequent human exposure through inhalation, dermal contact, or ingestion (Sangkham et al., 2022; Yang et al., 2022).

Among exposure routes, the ingestion of contaminated food stands out as one of the main entry points of these microparticles into the human body (Tang et al., 2024). Their presence has been documented across a wide range of food sources, including fish (Patidar et al., 2024; Jin et al., 2025), mollusks (Chinfak et al., 2024; Ribeiro et al., 2025), crustaceans (Amponsah et al., 2024; Mercy & Alam, 2024; Khan et al., 2025), vegetables (Conti et al., 2020; Bai et al., 2025), salt (Yang et al., 2015; Suteja et al., 2025), sugar and honey (Liebezeit & Liebezeit, 2013; Basaran et al., 2024a; Schuab et al., 2025), beer (Liebezeit & Liebezeit, 2014; Kosuth et al., 2018), milk and dairy products (Kutralam-Muniasamy et al., 2020; Visentin et al., 2024; Visentin et al., 2025), soft drinks (Altunisik, 2023; Basaran et al., 2024b; Hoseinzadeh et al., 2024; Ta et al., 2025), energy drinks (Shruti et al., 2020), tea (Hernandez et al., 2019; Chaïb et al., 2025), coffee (Al-Mansoori et al., 2025) and water (Mason et al., 2018; Schymanski et al., 2018; Samandra et al., 2022; Nocón et al., 2023). Once ingested, these microparticles and their associated contaminants can accumulate in the body (Yang et al., 2022), being detected in organs (Zhu et al., 2024; Oliveira et al., 2025), blood (Leslie et al., 2022), excretions (Schwabl et al., 2019; Huang et al., 2022; Massardo et al., 2024), human breast milk (Ragusa et al., 2022), and semen (Montano et al., 2023).

Given their potential adverse effects (Chakraborty et al., 2024; Chen et al., 2024), it is essential to identify the sources of human ingestion of these particles. Although this task is complex, it is known that plastic packaging and containers act as vectors of contamination, and consequently, of other pollutants in human food (Winkler et al., 2019; Du et al., 2020; Fadare et al., 2020). Additionally, the risk of contamination during the production of industrialized foods should be considered, due to the widespread presence of these particles in freshwater systems and the atmosphere (Amato-Lourenço et al., 2020; Altunisik, 2023).

Among globally consumed foods, industrialized beverages stand out, either due to potential contamination of raw materials or exposure to contaminants throughout the production process until reaching the final consumer (Adjama et al., 2024). In Brazil, research on anthropogenic microparticles has focused primarily on environmental contamination, including sediments (Gerolin et al., 2020; Camargo et al., 2022; Zanetti et al., 2025), aquatic systems (Garcia et al., 2020; Olivatto et al., 2024), and organisms (Mateos-Cárdenas et al., 2021; Schuab et al., 2023; Jankauskas et al., 2024; Rabelo et al., 2025). The presence of these particles has also been reported in organisms consumed by the population (Nunes et al., 2021; Bom & Sá, 2022; Alves & Figueiredo, 2023; Cruz et al., 2023) and in drinking water (Pratesi et al., 2021).

Quantification of human ingestion is challenging mainly due to uncertainty on the concentration of these particles in food items (Kwon et al., 2020; Socas-Hernández et al., 2024), a critical factor for health risk assessment (Eriksen et al., 2023). Despite this, there is a significant knowledge gap concerning the presence of these microparticles in industrialized beverages consumed in developing countries such as Brazil (Sewwandi et al., 2023). In this context, the present study aims to assess the abundance of these particles in different commercial beverages in Brazil, thereby allowing an estimation of the Brazilian population's exposure through ingestion.

2. Material and Methods

2.1 Samples

A total of six types of beverages, belonging to different categories and brands, were purchased from markets in the city of Vitória, state of Espírito Santo, Brazil. The samples included: two mineral waters from different brands, two beers from different brands, one lemon soda, two guaraná soda, one milk, one "orange-flavored" juice, and one apple pure juice. All beverages were purchased and analyzed in triplicate, a procedure considered appropriate for exploratory analyses of anthropogenic microparticles, allowing statistical validation of the results and assessment of variability among samples, totalizing 30 samples. Brand selection considered national coverage, taking into account their predominance and wide distribution in Latin America. Market sampling was conducted randomly to ensure overall representativeness of the local market and to avoid biases associated with specific production batches. This strategy aimed to reduce the possibility of detecting isolated contamination events from a single production line. The main characteristics of the samples, including packaging type, volume, and beverage category, are described in the Supplementary Material. Brand names were omitted for ethical reasons and to preserve the impartiality of the analysis.

2.2. Extraction of Anthropogenic Microparticles

AMPs were extracted from the samples using the filtration method described by Shruti et al. (2020). Samples were filtered using a vacuum pump and a 1.2 µm glass fiber membrane (GF/C Whatman), which allows the retention of the full size range reported in the literature for these particles (Frias & Nash, 2019) and requires less analysis time compared to smaller pore-size filters (0.47 µm), thereby reducing the risk of contamination. All filters were carefully transferred to pre-cleaned Petri dishes using stainless steel forceps (ABS STAINLESS L18- W4 0424), covered with aluminum foil, and dried in an oven at 50°C for 24 hours for subsequent analysis.

2.3. Characterization of Anthropogenic Microparticles

The filters were analyzed by visual inspection and documented photographically using a stereomicroscope equipped with a digital camera (Moticam Pro 252A). The entire surface of each filter was carefully examined, and detected microparticles were measured and classified according to their morphology (fibers, fragments, spheres/pellets, films, and foams) and color, following the identification protocols of GESAMP (2019), Lusher et al. (2020), and Miller et al. (2021). The morphological categories were defined as follows: fibers (elongated particles with length significantly greater than width), fragments (irregularly shaped particles resulting from the degradation of larger items), spheres/pellets (rigid, rounded, or spherical particles), films (flexible particles with smooth or angular edges), and foams (compressible particles that deform under pressure and return to their original shape). Size classification was performed using Motic Images Plus 3.0 software. To ensure accurate identification and avoid overestimation of anthropogenic microparticles, only particles meeting the following criteria were considered: homogeneous coloration, resistance to compression and heat, and absence of cellular structures, as proposed by Hidalgo-Ruz et al. (2012) and Beckingham et al. (2023). Furthermore, to ensure consistency in the analyses, all samples were evaluated under the supervision of the same researcher, minimizing subjectivity in microparticle identification.

2.4 Contamination prevention

Preventive contamination measures were taken during both sampling and laboratory analysis (Prata et al., 2021; Ta & Promchan, 2024). All flasks, beakers, Petri dishes, and filtration kits were pre-cleaned using distilled water that had been previously filtered through 1.2 µm pore size glass fiber filters (GF/C Whatman) to prevent the introduction of exogenous MPs during the process. Work surfaces were cleaned with 70% ethyl alcohol before and during the experiments. Doors and windows remained closed, and air conditioning units were turned off during the extraction and analysis of AMPs. Additionally, all glassware and equipment were covered with aluminum foil when not in use, as a precaution against the deposition of airborne particles. Blank tests were also conducted for all laboratory procedures and sample identifications, using glass fiber filters placed in open Petri dishes exposed to the air. In cases where contamination was detected in the blank tests, the corresponding values were subtracted from the respective samples. Throughout all stages of processing and analysis, the use of 100% cotton lab coats and latex gloves was mandatory to minimize secondary sources of contamination.

2.5 Statistical analysis

Analysis of variance (ANOVA) was conducted for assessing statistical differences among AMPs concentrations in different types of beverages, using RStudio software (RStudio Team, 2021). To meet the assumptions of normality, variance homogeneity, and independence, the original data were transformed using the Box-Cox method for calculating Euclidean distance between them. The variables included for analysis were: (i) types of beverages (beer, soda, juice, water and milk) (ii) types of beverages from different brands (beer1, beer2, fruit juice, pure fruit juice, guarana soda 1, guarana soda 2, lemon soda, milk, mineral water 1 and mineral water 2) (iii) types of packaging (carton, aluminum can and plastic). Tukey's post-hoc tests were performed to identify which pairs of groups differed from each other. Differences are considered statistically significant when $p < 0.05$.

2.6 Estimated Daily Intake of Anthropogenic Microparticles

The exposure of the Brazilian population to AMPs was estimated through the calculation of the Estimated Daily Intake (EDI), using an equation adapted from Socas-Hernández et al. (2024):

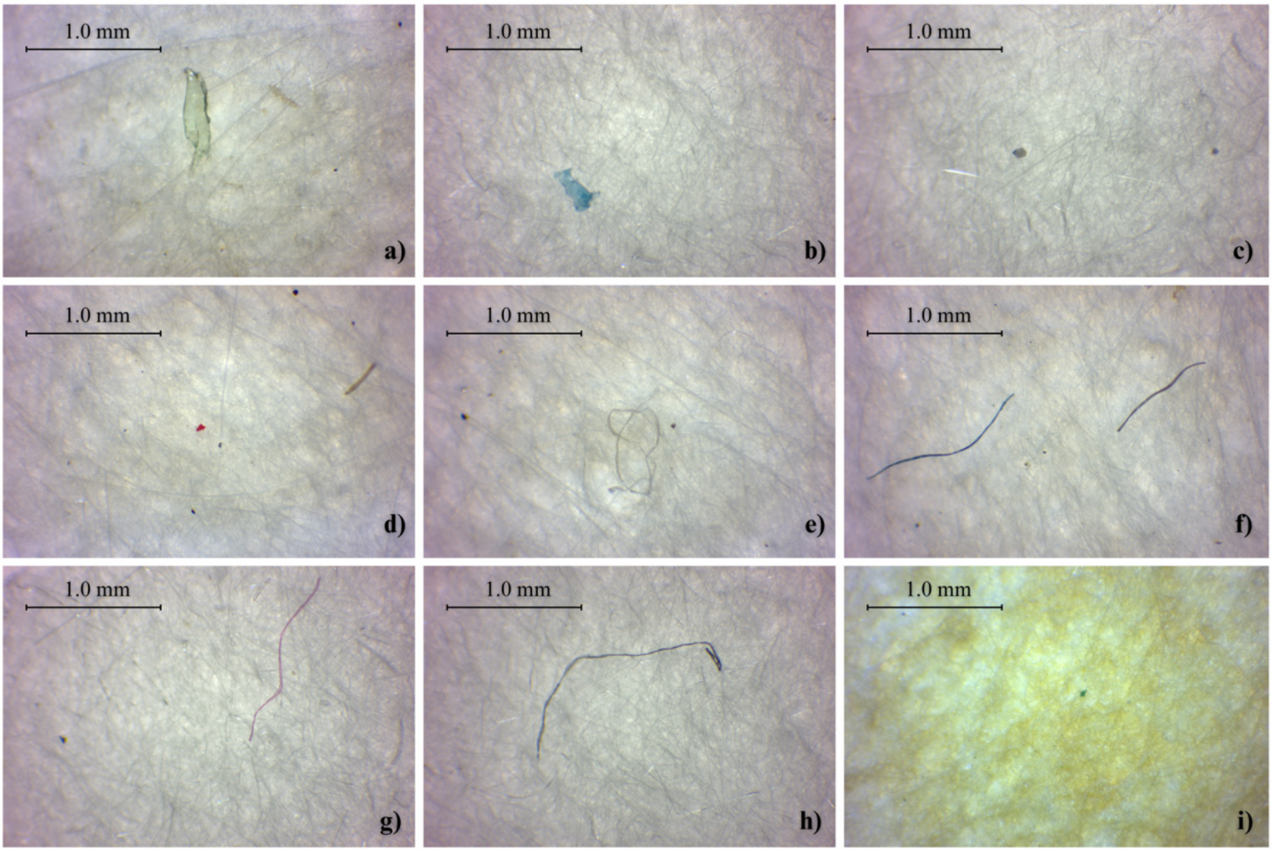
$$EDI\ \left(items.day.per\ capita^{-1}\right) = C\ .\ I$$

where C represents the mean concentration of AMPs (items.L^{-1}) and I corresponds to the average beverage consumption (L). Data on per capita beverage consumption in Brazil were obtained from Instituto Brasileiro de Geografia e Estatística, in portuguese (IBGE, 2019) and Serviço Geológico do Brasil (SGB). Since IBGE reports intake values in grams per day, an approximate mean density of 1 g.mL^{-1} was adopted for all beverages, allowing the conversion of values to liters (Socas-Hernández et al., 2024).

3. Results

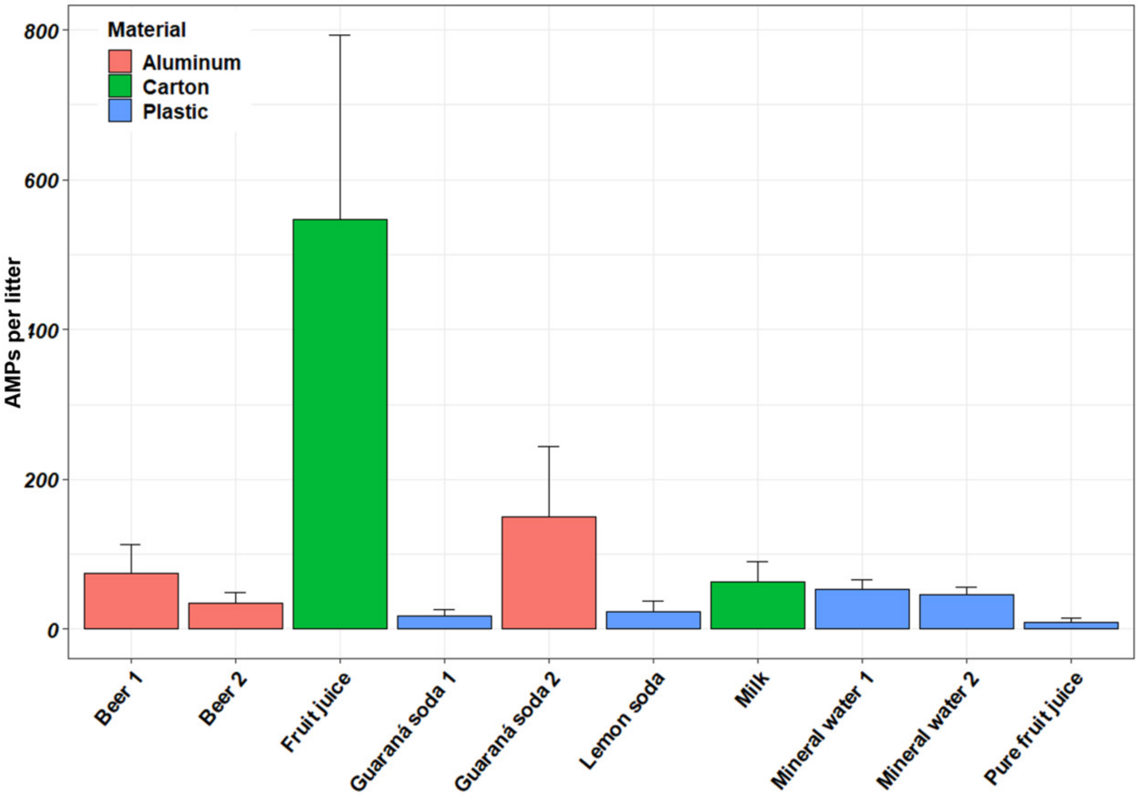
An average of 1.83 ± 1.84 AMPs was found in the blank tests, equally divided between fibers and fragments (50% each), with sizes ranging from 0.02 to 3.7 mm. These values were subtracted from the results of the beverage samples. A total of 589 anthropogenic microparticles were detected across the all analyzed samples, consisting of triplicates of ten beverages from different brands. All samples contained AMPs in various forms (fibers, fragments, films, pellets, and foams), sized, and colors. Examples of the particles identified are presented in Figure 1.

Figure 1. Photographs of anthropogenic microparticles detected during this study on different types of beverages. (A - D and I): fragment, (E - H): fiber.



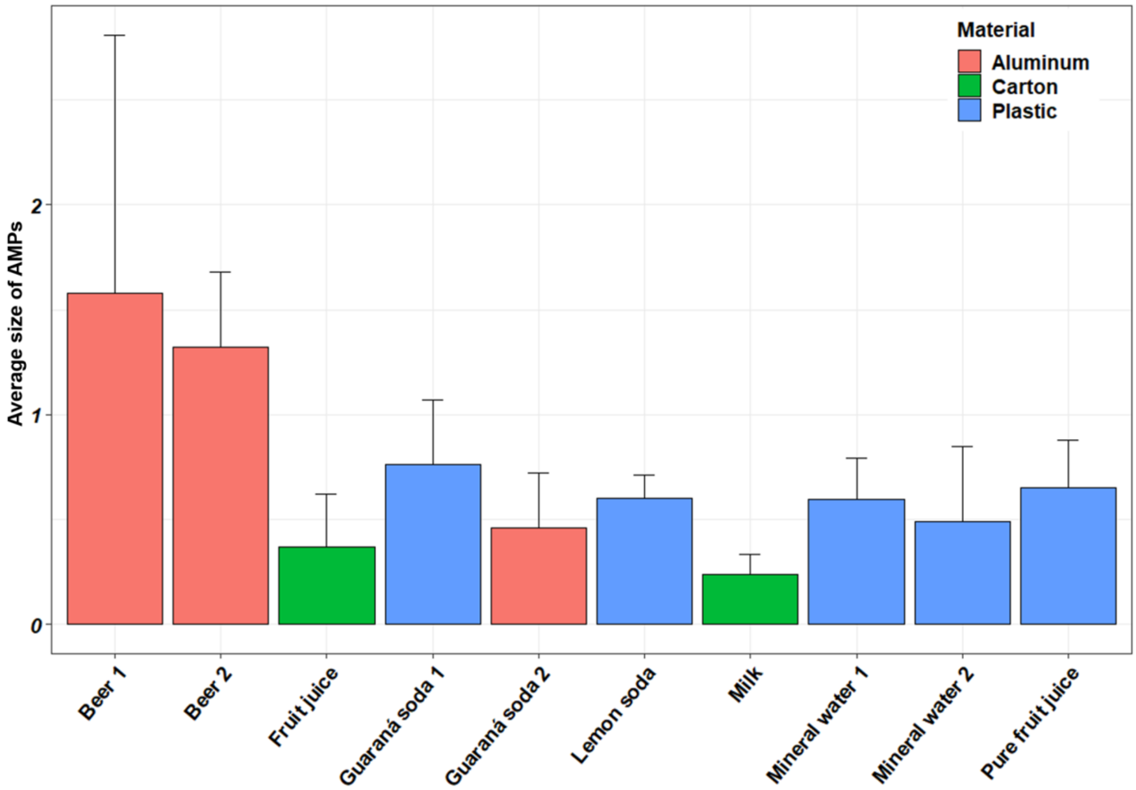
Mean AMPs concentrations varied widely among the beverages from different brands, ranging from 9.14 ± 9.4 to 547 ± 428 particles/L, which were also reflected in the grouped means of each beverage category: Beers (54.8 ± 49.9), Lemon soda (22.8 ± 25.2), Mineral water (49.2 ± 18.4), Milk (63.5 ± 46.5), Juices (277.9 ± 399.9), and Guaraná soda (84.4 ± 125.8). The highest concentrations were detected in the fruit-based drink packaged in a carton, while the lowest concentrations were observed in the pure fruit juice packaged in polyethylene terephthalate (PET) bottles (Figure 2).

Figure 2. Comparison of anthropogenic microparticles concentration (mean and standard variation) among beverages from different brands.



AMPs sizes ranged from 0.05 mm to 4.04 mm. Beer showed the largest particles and widest size range (0.32 to 4.04 mm), whereas milk contained the smallest particles, with a mean size of 0.24 mm and the narrowest range, from 0.09 mm to 0.41 mm (Figure 3). Regarding packaging type, beverages in carton packages exhibited the highest AMPs concentrations and the smallest particle sizes, while those in plastic bottles had the lowest concentrations, and those in aluminum cans presented larger particles (Figures 2 and 3).

Figure 3. Comparison of anthropogenic microparticles size (mean and standard deviation) among beverages from different brands.



Among the identified shapes, fragments were the most prevalent (62.5%), followed by fibers (31.9%), films (3%), and pellets (2%). Foams accounted for only 0.5% of the samples. The most frequently observed shape was fiber, detected in 96.7% of the samples, followed by fragments, present in 86.7%. A higher proportion of fragments was found in most of the analyzed beverages, except for Beer 2, pure fruit juice, and guaraná soda, which exhibited a greater abundance of fibers (Figure 4). Regarding color, AMPs were identified in black, blue, red, gray, pink, purple, yellow, brown, orange, white, and transparent. The most common colors across all beverages were black (53.3%) and blue (21.2%), although relative color dominance varied among beverages from different brands (Figure 5).

Analysis of variance (ANOVA) showed a significant difference among beverages analyzed from different brands (beer 1, beer 2, lemon soda, mineral water 1, milk, fruit drink, mineral water 2, bottled guaraná soda, canned guaraná soda and pure fruit juice). The Tukey test showed that the differences in AMPs concentration among the analyzed items were between the fruit drink and guarana soda, lemon soda, and pure juice, and also between the pure juice and the guarana soda. Regarding the different packaging (aluminum, carton and plastic), we found a significant difference between items packaged in carton and in plastic bottles ($p < 0.05$).

The estimated daily intake of AMPs by the Brazilian population, expressed as items.day^{-1}.*per capita*, was calculated for each beverage category based on the average of the different brands (Table 1). Juice contributed the most to AMPs intake, with a mean value of 39.18 items.day^{-1}.*per capita*. Water (14.27 items.day^{-1}.*per capita*) and soda (7.18 items.day^{-1}.*per capita*) also presented significant contributions. Beer (1.92 items.day^{-1}.*per capita*) and milk (1.02 items.day^{-1}.*per capita*) showed relatively low AMPs intake values. The sum of all beverage categories resulted in a total EDI of 63.57 items.day^{-1}.*per capita*, indicating a considerable exposure of the Brazilian population to anthropogenic microparticles through daily beverage consumption.

Figure 4. Comparison of the anthropogenic microparticles shape predominance (%) among beverages from different brands.

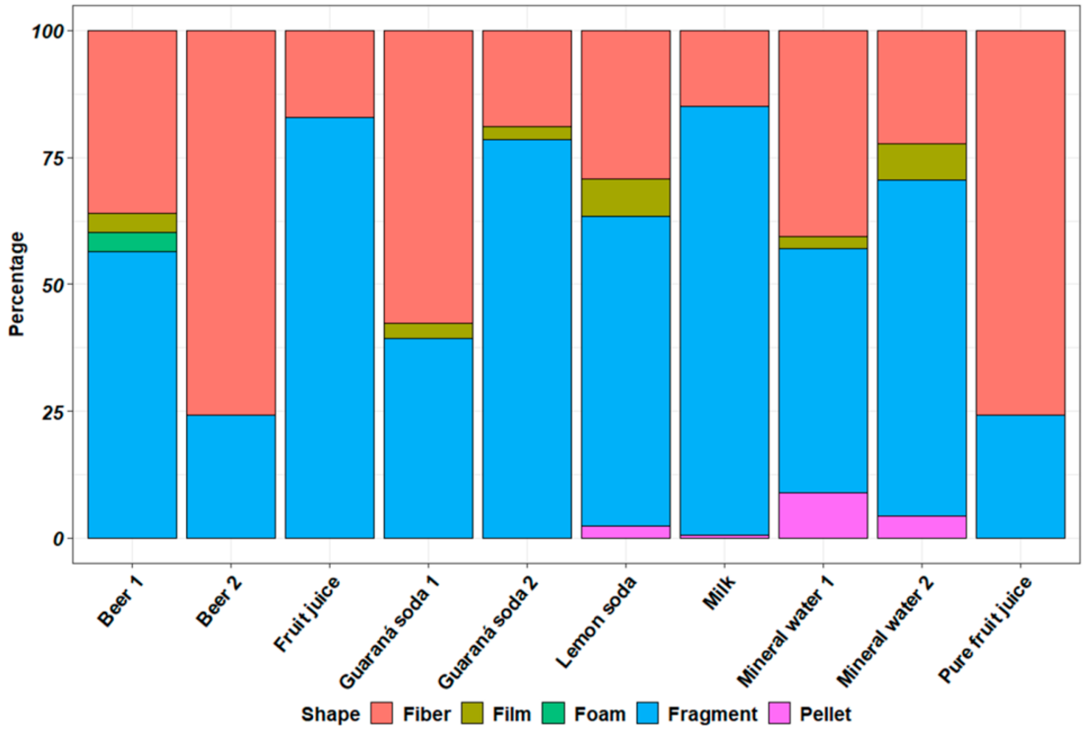


Figure 5. Comparison of the anthropogenic microparticles color predominance (%) among beverages from different brands.

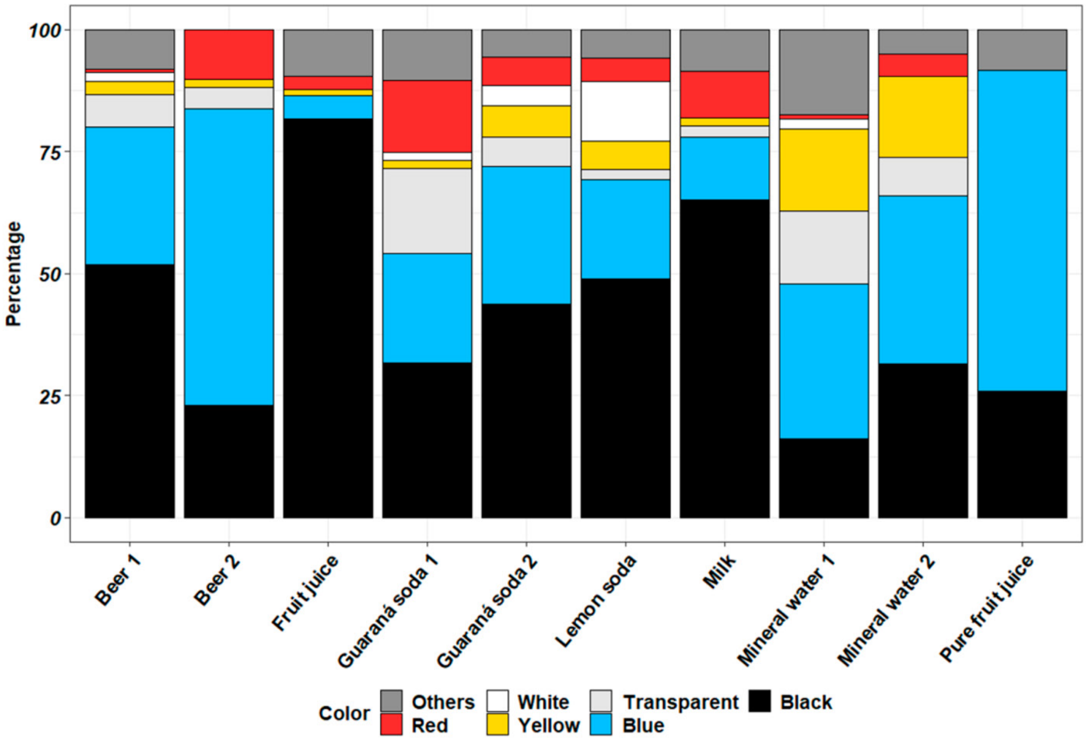


Table 1: Brazilian estimated daily intake (EDI) of anthropogenic microparticles (AMPs) from different beverage categories.

Beverage	***Per capita* intake (L/day)***	AMPs intake/day
Milk	0.016	1.016
Beer	0.035	1.918
Juice	0.141	39,184
Soda	0.067	7,182
Mineral water	0.29	14.269

*Data obtained from the Instituto Brasileiro de Geografia e Estatística (IBGE) and Serviço Geológico do Brasil (SGB

4. Discussion

The results of the present study suggest that AMPs contamination in industrially produced beverages in Brazil occurs regardless of beverage type or packaging material. All analyzed samples contained AMPs particles displaying a wide range of shapes, sizes and colors, indicating multiple potential sources of contamination (Basaran et al., 2024). The predominance of fragments and fibers, along with the diversity of colors, particularly black and blue, further supports the hypothesis of multiple origins. The highest concentrations of AMPs were observed in a fruit-based beverage packaged in multilayer carton and in beer stored in an aluminum can. Both samples showed a predominance of fragments, which may be attributed to the degradation of larger plastic items or the accidental introduction of AMPs during industrial processing (Mason et al., 2018; Sewwandi et al., 2023). In contrast, the lowest AMPs concentration was found in pure fruit juice packaged in a PET bottle.

Although plastic packaging is often associated with AMPs contamination, the results indicate that beverages stored in non-plastic materials, such as aluminum cans, also exhibited higher levels of AMPs compared to those packaged in plastic bottles. This finding suggests that contamination sources other than packaging material may play a substantial role in AMPs occurrence (Basaran et al., 2024). However, the highest AMPs concentration was observed in the fruit-based beverage packaged in a multilayer carton package. Since this type of packaging contains polyethylene layers in addition to paper and aluminum, the package itself may contribute to particle release during manufacturing, storage, transport, or handling, representing a potential source of contamination alongside industrial processing (Ma et al., 2024).

Despite this possibility, the present results do not allow the observed contamination to be directly attributed to the packaging material. Since polymer identification was not performed, it is not possible to determine whether the detected particles are chemically compatible with polyethylene layers present in carton packages or originate from other sources associated with beverage production and processing.

Differences in AMPs concentrations among beverages may be more closely related to the complexity of industrial processing than to packaging material. Beverages such as fruit-based drinks and soft drinks undergo multiple production, transport, and storage stages involving numerous ingredients and additives, increasing the number of potential contamination pathways (Shruti et al., 2020; Diaz-Basantes et al., 2020). Conversely, pure fruit juice, which exhibited the lowest AMPs concentration, generally undergoes less processing and has a simpler formulation.

The distribution of AMPs by shape and color observed in this study aligns with findings reported in several regions worldwide (Table 2). International studies have documented a wide range of AMPs concentrations in beverages, with high levels found in milk from India (Kiruba et al., 2022), Bangladesh (Chakravorty et al., 2024) and Italy (Visentin et al., 2025), beer from

Mexico (Shruti et al., 2020) and France (Chaïb., 2025), and soft drinks from Poland (Nocoń et al., 2023). Conversely, lower concentrations have been reported in fruit juices from China (Lam et al., 2024) and Turkey (Basaran et al., 2024), highlighting how differences in industrial processing methods and national regulatory frameworks can influence contamination levels.

Table 2: Comparison AMPs, including MPs, presence in industrialized beverages across different studies and countries. Conc. = Concentration; NI = Not informed. (continued).

Country	Beverages	Conc. (average ± SD)	Size (µm)	Shape	Colors	Reference
Germany	Beer	Fiber: 2 - 79 Fragment: 12 - 109 Granules: 2 - 66	NI	Fiber, fragment and granules	NI	Liebezeit e Liebezeit, 2014
USA, Italy, India, Mexico, United Kingdom, France, Germany, Libyan, Brazil and China	Mineral water	7 ± 47	6.5 - 100	Fragment, fiber, foam	NI	Mason et al., 2018
Germany	Mineral water	2649 ± 2857	≤1.5 – 5	Fragment	Blue, yellow, violet and red	Oßmann et al., 2018
Germany	Mineral water (PET and TetraPak)	PET: 14 ± 14 TetraPak: 11 ± 8	5 – 20	Fragment	NI	Schymanski et al., 2018
Ecuador	Milk, beer and soda	Milk: 40 Soda: 32 Beer: 47	13.45 - 6741.48	Fiber and Fragment	Green, yellow, red, violet and blue	Diaz-Basantes et al., 2020
Thailand	Water	140 ± 19	6.5 - >50	Fibers and fragments	Transparent, blue and brown	Kankanige & Babel, 2020
Mexico	Milk	6.5 ± 2.3	<500 - 2000	Fiber and fragment	Blue, red, pink and brown	Kutralam-Muniasamy et al., 2020
Mexico	Soda and beer	Soda: 40 ± 24.53 Beer: 152 ± 50.97	100 - 3000	Fibrer and fragment	Blue, brown, red, green and black	Shruti et al., 2020

Country	Beverages	Conc. (average ± SD)	Size (µm)	Shape	Colors	Reference
Thailand	Water	140 ± 19	6.5 - 100	Fibers and fragments	Blue, green, red, brown, black and transparent	Kankanige & Babel, 2020
Ira	Water	8.5 ± 10.2	NI	Fragment and fiber	White, transparent and black	Makhdoumi et al., 2021
India	Milk	301	< 500	Fiber, fragment and pellet	Pink, purple and blue	Kiruba et al., 2022
Malaysia	Water	11.7 ± 4.6	25 - 5000	Fragment and fiber	Transparent, blue and green	Praveena et al., 2022
Australia	Water	13 ± 19	77 ± 22	Fragments and fibers	NI	Samandra et al., 2022
Turkey	Soda (PET e Tetra Pak)	8.9 ± 2.95	10 – 1000	Fragment, fiber and foam	Transparent, blue, grey, red, black, green and yellow	Altunisik, 2023
Turkey	Milk	6 ± 5	25 - 5050	Fiber and fragment	Black, green, brown, grey, blue and red	Basaran et al., 2023
Italy	Soda	9.94 ± 0.33	36 - 2228	Fiber and fragment	NI	Crosta et al., 2023
Polski	Soda and water	Soda: 1000 - 1500 Water: 4167 - 14556	NI	Fiber and fragment	NI	Nocoń et al., 2023
Turkey	Mineral water and soda	Mineral water: 1.13 Soda: 0.30	Water: 470 - 970	Fiber e fragment	Blue, transparent, black, green, red and white	Basaran et al., 2024
Ira	Soda	21.90 ± 25.72	1 - 1500	Fiber and fragment	Black, red and green	Hoseinzadeh et al., 2024
China	Juice and soda	Juice: 30 ± 28.5 Soda: 49.3 ± 54.5	30 - 4257.1	Foam, fragment and fiber	Transparent, white, red, pink, purple, orange, yellow, green, blue and black	Lam et al., 2024

Country	Beverages	Conc. (average ± SD)	Size (µm)	Shape	Colors	Reference
Bangladesh	Milk	182.27 ± 55.13	<1000 - <1000	Fiber, fragment and film	Transparent, black, red, blue, white, green, yellow and violet	Chakravorty et al., 2024
United Kingdom	Juice and Soda	Juice: 30 ± 11 Soda: 17 ± 4	Juice: 33.1 ± 21.9 Soda: 31.0 ± 12.8	Fragment and fiber	-	Al-Mansoori et al., 2025
France	Water, Soda, Lemonade, and Beer	Water: 2.9 ± 0.7 Soda: 31.4 ± 16 Lemonade: 45.2 ± 21.4 Beer: 82.9 ± 13.9	30 - 500	Fiber and fragment	-	Chaïb et al., 2025
Italy	Milk	350 ± 529.9	24 - 4817	Fragment, fiber and pellets	Grey, brown, black, blue, red and transparent	Visentin et al., 2025
South Africa	Alcoholic beverages and Non-alcoholic Beverages	15 ± 7,6	20 – 3000	Fibers, fragments, granules and films	Black, gray, blue, red and green	Ramaremisa et al., 2025
Thailand	Soda	2 ± 3 to 39 ± 10	50 - 2000	Fragments, fiber and sphere	-	Ta et al., 2025
Brazil	Beer, juice, soda lemonade, milk, mineral water and soda guarana	Beer: 54.8 ± 49.9; Soda Lemonade: 22.8 ± 25.2; Juice: 277.9 ± 399.9; Milk: 63.5 ± 46.5; Mineral water: 49.2 ± 18.4; Soda guarana: 84.4 ± 125.8.	50 - 4040	Fragment, fiber, foam, pellets and foam	Black, blue, red, grey, pink, yellow, brown, orange, purple, white and transparent	Present study

According to Lam et al. (2024), the presence of AMPs in industrially produced beverages is to be expected, given that water, an essential component of these formulations, can serve as a primary source of contamination. However, the persistence of contamination even after water filtration remains a relevant concern, particularly due to atmospheric deposition in industrial settings, where synthetic particle concentrations in the air are notably high (Dris et al., 2017; Enyoh et al., 2019).

The predominance of fragments observed in the present study supports this hypothesis, as this particle type is typically associated with degradation processes occurring in the environment (Thompson et al., 2004; Browne et al., 2007; Andrady, 2011). Additional sources of AMPs include fibers shed from workers' clothing, equipment wear, plastic containers used for ingredient storage (Oßmann et al., 2018; Altunisik, 2023; Sobhani et al., 2020), and even specific processing steps, such as filtration in dairy production (Kutralam-Muniasamy et al., 2020). Mechanical abrasion and the fragility of packaging materials may also contribute to AMPs release during storage and transportation (Schymanski et al., 2018; Winkler et al., 2019).

In the present study, beverages packaged in multilayer cartons contained smaller particles, whereas those in aluminum cans exhibited AMPs of marger dimensions, likely reflecting differences in manufacturing processes (Sewwandi et al., 2023). This finding is particularly relevant because the smallest particles were observed in the beverage category that exhibited the highest AMPs concentrations. The combination of high particle abundance and reduced particle size suggests a possible contribution from sources associated with industrial processing and bottling operations. Additionally, fibers were predominant in beverages packaged in PET bottles, a pattern previously described by Du et al. (2020) and confirmed in this study, where fiber particles were prevalent in samples of pure fruit juice and guarana soda 2.

The high variability observed in the data, as indicated by the large standard deviations, can be attributed to the randomness of production batches, which may have directly influenced the results. This suggests that isolated contamination events likely occurred in some samples. The exceptionally high variability observed in the juicy category may indicate that contamination is not uniformly distributed throughout the production chain, but rather results from sporadic contamination events occurring at specific manufacturing or bottling stages. Such variability is expected in studies of this nature and reinforces the need for broad and continuous monitoring to understand AMPs contamination as a dynamic and multifactorial phenomenon.

The choice of packaging materials for food products directly affects both product quality and shelf life (Salgado et al., 2021). Despite advances in research aimed at reducing the use of plastic packaging and replacing it with bio-based alternatives, the final cost of non-plastic packaging remains economically unfeasible for the industry (Ghaani et al., 2016; Abdulla et al., 2024). Thus, the resources saved through the use of conventional materials, such as plastics, could instead be invested in improving production processes, for example, by installing filtration systems capable of retaining microplastics before bottling. Giri et al. (2024) highlights that control and prevention measures for AMPs pollution have progressed promisingly, with technological, biological, or hybrid solutions; however, their effectiveness depends on coordinated global efforts.

The results obtained reveal that the intake of AMPs by the Brazilian population is strongly influenced by the type of beverage consumed. Juice stood out as the main source of exposure, presenting both high per capita consumption values and elevated AMPs concentrations. In contrast, the low contributions observed for beer and milk likely reflect both lower per capita consumption and reduced AMPs concentrations compared with the other beverages analyzed.

The total EDI value was 63.57 items·day^{-1}·*per capita*, corresponding to approximately 23,202 items·year^{-1}·*per capita*. This value is lower than the estimates reported by Cox et al. (2019), who found annual intakes ranging from 39,000 to 52,000 particles in the United States when considering both food and beverages. Regional differences in cultural, economic, and social patterns, as well as in production and consumption practices, may account for part of this discrepancy. From a toxicological and risk assessment perspective, although the annual intake estimated for the Brazilian population is lower than that reported by Cox et al. (2019), the data indicate continuous and daily exposure to anthropogenic microparticles, underscoring the importance of further investigations into their potential effects on human health.

In addition to environmental concerns, the presence of AMPs in beverages poses a potential risk to public health. These particles can interact with contaminants such as phthalates and bisphenol, substances commonly associated with plastics and already detected in processed food and beverages (Teuten et al., 2009; Lithner et al., 2011; Sewwandi et al., 2023). Their ingestion, therefore, raises significant concerns regarding food safety (Du et al., 2020).

In this context, the development and implementation of effective practices to mitigate contamination are essential, along with the promotion of awareness campaigns and long-term research assessing human exposure to AMPs through the consumption of processed beverages. Furthermore, future studies should prioritize the chemical characterization of particles using techniques such as FTIR and Raman spectroscopy, allowing the identification of polymer composition and providing a more accurate understanding of the relative contributions of packaging materials, industrial equipment, and other stages of the production chain to the contamination observed in beverages.

5. Conclusion

This is the first study to report the presence of anthropogenic microparticles contamination in various industrialized beverages in Brazil, and also the first to present an EDI of these particles by the Brazilian population. The high proportion of AMPs found highlights the need for practical strategies to regulate industrial processes and prevent contamination of human consumables. Among potential measures, the development of packaging that minimizes AMPs contamination and the implementation of more efficient filtration systems during industrial processing to reduce particle concentrations in the final product are noteworthy. It is further suggested for public policies that packaging for products intended for human consumption starts to include information regarding the presence or absence of anthropogenic particles, thereby promoting greater transparency and consumer awareness. Although this study has provided relevant data on the presence of AMPs in industrialized beverages, it was not possible to perform chemical characterization of the microparticles using FTIR, Raman spectroscopy, or pyrolysis-GC-MS due to the unavailability of equipment. Such analyses are recognized as essential to confirms the composition of microparticles and to gain better understanding of their origin. The morphological and heat resistance criteria used to identify microparticles as anthropogenic, widely employed in the literature, are feasible and coherent. Nevertheless, the morphological results obtained make a significant contribution to advancing this topic in Brazil. Finally, through the evaluation of the EDI, it was found that the Brazilian is exposed daily to the consumption of anthropogenic microparticles, such as microplastics, which may pose risks to human health. These results reinforce the need for future studies incorporating spectroscopic techniques to improve the accuracy of contaminant identification and to strengthen mitigation strategies.

6. Ackowledgements

This work was funded by the Science and Technology Bureau of Espírito Santo State (Fundação de Amparo à Pesquisa do Espírito Santo - FAPES) and Coordination for the Improvement of Higher Educational Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES). We also thank the São Domingos school for their partnership in carrying out the study.

7. References

Abdulla, S. F.; Shams, R.; Dash, K. K. Edible packaging as sustainable alternative to synthetic plastic: a comprehensive review. **Environmental Science and Pollution Research**, 1-15, 2024. https://doi.org/10.1007/s11356-024-32806-z

Adjama, I.; Dave, H.; Balarabe, B. Y.; Masiyambiri, V.; Marycleopha, M. Microplastics in dairy products and human breast milk: Contamination status and greenness analysis of available analytical methods. **Journal of Hazardous Materials Letters**, 100120, 2024. https://doi.org/10.1016/j.hazl.2024.100120

Al-Mansoori, M.; Harrad, S.; Abdallah, A. Synthetic microplastics in hot and cold beverages from the UK market: Comprehensive assessment of human exposure via total beverage intake. **Science of the Total Environment**, 996, 180188, 2025 https://doi.org/10.1016/j.scitotenv.2025.180188

Altunisik, A. Prevalence of microplastics in commercially sold soft drinks and human risk assessment. **Journal of Environmental Management**, 336, 117720, 2024. https://doi.org/10.1016/j.jenvman.2023.117720

Alves, V. E. N.; Figueiredo, G. M. Assessment of microplastic impacts on whitemouth croaker (*Micropogonias furnieri*) and ecosystem services in Guanabara Bay, Brazil. **Environmental Biology of Fishes**, 106, 2177-2192, 2023. https://doi.org/10.1007/s10641-023-01497-9

Amato-Lourenço, L. F.; Galvão, L. S.; Weger, L. A.; Hiemstra, P. S.; Vijver, M. G.; Mauad, T. An emerging class of air pollutants: Potential effects of microplastics to repiratory human health?. **Science of the Total Environment**, 749, 141676, 2020. https://doi.org/10.1016/j.scitotenv.2020.141676

Amponsah, A. K.; Afrifa, E. K. A.; Essandoh, P. K. Plastic in the food chain: Investigating microplastic consumption by the blue-swimming crab (de Rochebrune, 1883) and shrimp (Pérez-Farfante, 1967) from an estuarine system in Ghana. **Scientific African**, 25, e02261, 2024. https://doi.org/10.1016/j.sciaf.2024.e02261

Andrady, A. L. Microplastics in the marine environment. **Marine Pollution Bulletin**, 62 (8), 1596–1605, 2011. https://doi.org/10.1016/j.marpolbul.2011.05.030

Andrady, A. L. The plastic in microplastics: A review. **Marine Pollution Bulletin**, 119, 12-22, 2017. https://doi.org/10.1016/j.marpolbul.2017.01.082

Athey, S. N.; Erdle, L. M. Are We Underestimating Anthropogenic Microfiber Pollution? A Critical Review of Occurrence, Methods, and Reporting. **Environmental Toxicology and Chemistry**, v. 41, n. 4, p. 822-837, 2022. https://doi.org/10.1002/etc.5173

Bai, Y.; Song, Y.; He, X.; He, W.; Chen, Y.; Zhao, M.; Zhang, J.; Han, W; Bai, W. Evidence of microplastic accumulation on the surface of lettuce and analysis of contamination sources. **Journal of Hazardous Materials**, 492, 138201, 2025. https://doi.org/10.1016/j.jhazmat.2025.138201

Basaran, B.; Aytan, Ü.; Şentürk, Y.; Özçifçi, Z.; Akçay, H. T. Microplastic contamination in some beverages marketed in türkiye: Characteristics, dietary exposure and risk assessment. **Food and Chemical Toxicology**, 189, 114730, 2024. https://doi.org/10.1016/j.fct.2024.114730

Basaran, B.; Özçifçi, Z.; Akcay, H. T.; Aytan, Ü. Microplastics in branded milk: Dietary exposure and risk assessment. **Journal of Food Composition and Analysis**, 123, 105611, 2023. https://doi.org/10.1016/j.jfca.2023.105611

Basaran, B.; Özçifçi, Z.; Kanbur, E. D.; Akçay, H. T.; Gül, S.; Bektaş, Y.; Aytan, Ü. Microplastics in honey from Türkiye: Occurrence, characteristic, human exposure, and risk assessment. **Journal of Food Composition and Analysis**, 135, 106646, 2024. https://doi.org/10.1016/j.jfca.2024.106646

Beckingham, B.; Apintiloaiei, A.; Moore, C.; Brandes, J. Hot or not: systematic review and laboratory evaluation of the hot needle test for microplastic identification. **Microplastics and Nanoplastics**, 3(1), 8, 2023. https://doi.org/10.1186/s43591-023-00056-4

Bom, F. C.; Sá, F. Are bivalves a source of microplastics for humans? A case study in the Brazilian markets. **Marine Pollution Bulletin**, 181, 113823, 2022. https://doi.org/10.1016/j.marpolbul.2022.113823

Browne, M. A.; Crump, P.; Niven, S. J.; Teuten, E.; Tonkin, A.; Galloway, T.; Thompson, R. Accumulation of microplastic on shorelines woldwide: sources and sinks. **Environmental science & technology**, 45(21), 9175-9179, 2011. https://doi.org/10.1021/es201811s

Browne, M. A.; Galloway, T.; Thompson, R. Microplastic—an emerging contaminant of potential concern?. **Integrated environmental assessment and Management**, 3(4), 559-561, 2007. https://doi.org/10.1002/ieam.5630030411

Camargo, A. L. G.; Girard, P.; Sanz-Lazaro, C.; Silva, A. C. M.; De Faria, É.; Figueiredo, B. R. S.; ... Blettler, M. C. Microplastics in sediments of the Pantanal Wetlands, Brazil. **Frontiers in Environmental Science**, 10, 1017480, 2022. https://doi.org/10.3389/fenvs.2022.1017480

Campanale, C.; Massarelli, C.; Savino, I.; Locaputo, V.; Uricchio, V. F. A detailed review study on potential effects of microplastics and additives of concern on human health. **International journal of environmental research and public health**, 17(4), 1212, 2020. https://doi.org/10.3390/ijerph17041212

Chaïb, I.; Doyen, P.; Merveillie, P.; Dehaut, A; Duflos, G. Microplastic contaminations in a set of beverages sold in France. **Journal of Food Composition and Analysis**, 144, 107719, 2025. https://doi.org/10.1016/j.jfca.2025.107719

Chakraborty, S.; Banerjee, M.; Jayaraman, G. Evaluation of the health impacts and deregulation of signaling pathways in humans induced by microplastics. **Chemosphere**, 369, 143881, 2024. https://doi.org/10.1016/j.chemosphere.2024.143881

Chakraborty, T. K.; Hasan, M. J.; Netema, B. N.; Rayhan, M. A.; Asif, S. M. H.; Biswas, A.; ... Hasibuzzaman, M. Microplastics in the commercially available branded milk in Bangladesh: An emerging threat for human health. **Journal of Hazardous Materials**, 477, 135374, 2024. https://doi.org/10.1016/j.jhazmat.2024.135374

Chen, G.; Li, X.; Wang, Z.; Li, M.; Wang, W.; Lu, R.; Wang, S.; Li, Q.; Hu, Z.; Wu, Y.; Li, Z.; Wang, P.; Cao, Y. Human exposure to micro(nano)plastics: Health risks and analysis methods. **TrAC Trends in Analytical Chemistry**, 178, 117835, 2024. https://doi.org/10.1016/j.trac.2024.117835

Chinfak, N.; Charoenpong, C.; Sampanporn, A.; Wongpa, C.; Sompongchaiyakul, P. Microplastics in commercial bivalves from coastal areas of Thailand and health risk associated with microplastics in ingested bivalves. **Marine Pollution Bulletin**, 208, 116937, 2024. https://doi.org/10.1016/j.marpolbul.2024.116937

Conti, G. O.; Ferrante, M.; Banni, M.; Favara, C.; Nicolosi, I.; Cristaldi, A.; ... Zuccarello, P. Micro-and nano-plastics in edible fruit and vegetables. The first diet risks assessment for the general population. **Environmental research**, 187, 109677, 2020. https://doi.org/10.1016/j.envres.2020.109677

Crosta, A.; Parolini, M.; De Felice, B. Microplastics contamination in nonalcoholic beverages from the Italian Market. **International Journal of Environmental Research and Public Health**, 20(5), 4122, 2023. https://doi.org/10.3390/ijerph20054122

da Cruz, B. R. F.; Nogueira, C. S.; Bueno, A. A. P.; Jacobucci, G. B. Natural diet of the freshwater prawn Macrobrachium amazonicum (Heller, 1862) in the Rio Grande, southeastern Brazil. **Studies on Neotropical Fauna and Environment**, 59(3), 931-940, 2024. https://doi.org/10.1080/01650521.2023.2286677

De-la-Torre, G. E. Microplastics: an emerging threat to food security and human health. **Journal of food science and technology**, 57(5), 1601-1608, (2020). https://doi.org/10.1007/s13197-019-04138-1

Diaz-Basantes, M. F.; Conesa, J. A.; Fullana, A. Microplastics in honey, beer, milk and refreshments in Ecuador as emerging contaminants. **Sustainability**, 12(14), 5514, 2020. https://doi.org/10.3390/su12145514

Dris, R.; Gasperi, J.; Mirande, C.; Mandin, C.; Guerrouache, M.; Langlois, V.; Tassin, B. A first overview of textile fibers, including microplastics, in indoor and outdoor environments. **Environmental pollution**, 221, 453-458, 2017. https://doi.org/10.1016/j.envpol.2016.12.013

Du, F.; Cai, H.; Zhang, Q.; Chen, Q.; Shi, H. Microplastics in take-out food containers. **Journal of Hazardous Materials**, 399, 122969, 2020. https://doi.org/10.1016/j.jhazmat.2020.122969

Enyoh, C. E.; Verla, A. W.; Verla, E. N.; Ibe, F. C.; Amaobi, C. E. Airborne microplastics: a review study on method for analysis, occurrence, movement and risks. **Environmental monitoring and assessment**, 191, 1-17, 2019. https://doi.org/10.1007/s10661-019-7842-0

Eriksen, M.; Cowger, W.; Erdle, L. M.; Coffin, S.; Villarrubia-Gómez, P.; Moore, C. J.; ... Wilcox, C. A growing plastic smog, now estimated to be over 170 trillion plastic particles afloat in the world's oceans—Urgent solutions required. **Plos one**, 18(3), e0281596, 2023. https://doi.org/10.1371/journal.pone.0281596

Fadare, O. O.; Wan, B.; Guo, L. H.; Zhao, L. Microplastics from consumer plastic food containers: are we consuming it?. **Chemosphere**, 253, 126787, 2020. https://doi.org/10.1016/j.chemosphere.2020.126787

Finnegan, A. M. D.; Susserott, R.; Gabbott, S. E.; Gouramanis, C. Man-made natural and regenerated cellulosic fibers greatly outnumber microplastic fibres in the armosphere. **Environmental Pollution**, v. 310. 2022. https://doi.org/10.1016/j.envpol.2022.119808

Frias, J. P.; Nash, R. Microplastics: Finding a consensus on the definition. **Marine pollution bulletin**, *138*, 145-147, 2019. https://doi.org/10.1016/j.marpolbul.2018.11.022

Fu, Z.; Wang, J. Current practices and future perspectives of microplastic pollution in freshwater ecosystems in China. **Science of the Total Environment**, 691, 697-712, 2019. https://doi.org/10.1016/j.scitotenv.2019.07.167

Garcia, T. M.; Campos, C. C.; Mota, E. M. T.; Santos, N. M. O.; de Santana Campelo, R. P.; Prado, L. C. G.; ... de Oliveira Soares, M. Microplastics in subsurface waters of the western equatorial Atlantic (Brazil). **Marine Pollution Bulletin**, 150, 110705, 2020. https://doi.org/10.1016/j.marpolbul.2019.110705

Gerolin, C. R.; Pupim, F. N.; Sawakuchi, A. O.; Grohmann, C. H.; Labuto, G.; Semensatto, D. Microplastics in sediments from Amazon rivers, Brazil. **Science of the Total Environment**, 749, 141604, 2020. https://doi.org/10.1016/j.scitotenv.2020.141604

Ghaani, M.; Cozzolino, C. A.; Castelli, G.; Farris, S. An overview of the intelligent packaging technologies in the food sector. **Trends in Food Science & Technology**, 51, 1-11, 2016. https://doi.org/10.1016/j.tifs.2016.02.008

Giri, S.; Lamichhane, G.; Khadka, D.; Devkota, H. P. Microplastics contamination in food products: Occurrence, analytical techniques and potential impacts on human health. **Current Research in Biotechnology**, 100190, 2024. https://doi.org/10.1016/j.crbiot.2024.100190

Hernandez, L. M.; Xu, E. G.; Larsson, H. C.; Tahara, R.; Maisuria, V. B.; Tufenkji, N. Plastic teabags release billions of microparticles and nanoparticles into tea. **Environmental science & technology**, 53(21), 12300-12310, 2019. https://doi.org/10.1021/acs.est.9b02540

Hidalgo-Ruz, V.; Gutow, L.; Thompson, R. C.; Thiel, M. Microplastics in the marine environment: a review of the methods used for identification and quantification. **Environmental science & technology**, 46(6), 3060-3075, 2012. https://doi.org/10.1021/es2031505

Hoseinzadeh, E.; Hossini, H.; Makhdoumi, P.; Parsa, S.; Massahi, T. Microplastics contamination in popular soft drinks and non-alcoholic beverages marketed in Iran: Quantity and characteristics. **Results in Engineering**, 24, 103158, 2024. https://doi.org/10.1016/j.rineng.2024.103158

Huang, S.; Huang, X.; Bi, R.; Guo, Q.; Yu, X., Zeng, Q.; ... Guo, P. Detection and analysis of microplastics in human sputum. **Environmental science & technology**, 56(4), 2476-2486, 2022. https://doi.org/10.1021/acs.est.1c03859

Instituto Brasileiro de Geografia e Estatística (IBGE), Coordenação de Trabalho e Rendimento. Pesquisa de orçamentos familiares 2017-2018: análise do consumo alimentar pessoal no Brasil [Analysis of personal food consumption in Brazil: Household Budget Survey 2017-2018] (120 pp.). Rio de Janeiro: IBGE. ISBN 978-65-87201-15-3. Retrieved September 9, 2025, from https://static.poder360.com.br/2024/12/pesquisa-de-orcamentos-familiares-2017-2018-ibge.pdf

Jankauskas, L.; Pinho, G. L. L.; Sanz-Lazaro, C.; Casado-Coy, N.; Rangel, D. F.; Ribeiro, V. V.; Castro, Í. B. Microplastic in clams: An extensive spatial assessment in south Brazil. **Marine Pollution Bulletin**, 201, 116203, 2024. https://doi.org/10.1016/j.marpolbul.2024.116203

Jin, R.; Li, L.; Wang, S.; Hu, M.; Huang, W; Wang, Y. Microplastic accumulation in four commercial fish from fish market: Implications for human dietary risk assessment. **Food Control**, 176, 111332, 2025. https://doi.org/10.1016/j.foodcont.2025.111332

Kankanige, D.; Babel, S. Smaller-sized micro-plastics (MPs) contamination in single-use PET-bottled water in Thailand. **Science of the total environment**, 717, 137232, 2020. https://doi.org/10.1016/j.scitotenv.2020.137232

Karbalaei, S.; Hanachi, P.; Walker, T. R.; Cole, M. Occurrence, sources, human health impacts and mitigation of microplastic pollution. **Environmental science and pollution research**, 25, 36046-36063, 2018. https://doi.org/10.1007/s11356-018-3508-7

Kershaw, P. J.; Turra, A.; Galgani, F. Guidelines for the monitoring and assessment of plastic litter and microplastics in the ocean. 2019. http://dx.doi.org/10.25607/OBP-435

Khan, M. S.; Marma, T. U.; Sumi, S. N.; Chisim, A.; Shakib, I. A; Rana, S. Plastic in seafood: are crustaceans a gateway to microplastic exposure in humans?. **Science in One Health**, 4, 100121, 2025. https://doi.org/10.1016/j.soh.2025.100121

Kim, D.; Kim, H.; An, Y. Effects of synthetic and natural microfibers on Daphnia magna-Are they dependent on microfiber type?. *Aquatic Toxicology, 240,* 105968. https://doi.org/10.1016/j.aquatox.2021.105968

Kiruba, R.; Preethi, M.; Aganasteen, R.; Rithick Raj, M.; Hannah Thabitha, C.; Monica, P.; ... Naseera Banu, I. Identification of microplastics as emerging contaminant in branded milk of Tamil Nadu State, India. **Asian Journal of Biological and Life Sciences**, 11(1), 181, 2022.

Kosuth, M.; Mason, S. A.; Wattenberg, E. V. Anthropogenic contamination of tap water, beer, and sea salt. **PloS one**, 13(4), e0194970, 2018. https://doi.org/10.1371/journal.pone.0194970

Kumar, R.; Manna, C.; Padha, S.; Verma, A.; Sharma, P.; Dhar, A.; Ghosh, A.; Bhattacharya, P. Micro(nano)plastics pollution and human health: How plastics can induce carcinogenesis to humans?. **Chemosphere**, 298, 134267, 2022. https://doi.org/10.1016/j.chemosphere.2022.134267

Kutralam-Muniasamy, G.; Pérez-Guevara, F.; Elizalde-Martínez, I.; Shruti, V. C. Branded milks–Are they immune from microplastics contamination?. **Science of the Total Environment**, 714, 136823, 2020. https://doi.org/10.1016/j.scitotenv.2020.136823

Kwon, J. H.; Kim, J. W.; Pham, T. D.; Tarafdar, A.; Hong, S.; Chun, S. H.; ... Jung, J. Microplastics in food: a review on analytical methods and challenges. **International journal of environmental research and public health**, 17(18), 6710, 2020. https://doi.org/10.3390/ijerph17186710

Lam, T. W. L., Chow, A. S. Y., & Fok, L. (2024). Human exposure to microplastics via the consumption of nonalcoholic beverages in various packaging materials: the case of Hong Kong. *Journal of Hazardous Materials*, 472, 134575. https://doi.org/10.1016/j.jhazmat.2024.134575

Lee, J.; Chia, R. W.; Veerasingam, S.; Uddin, S.; Jeon, W.; Moon, H. S.; Cha, J.; Lee, J. A comprehensive review of urban microplastic pollution sources, environment and human health impacts, and regulatory efforts. **Science of the Total Environment**, 946, 174297, 2024. https://doi.org/10.1016/j.scitotenv.2024.174297

Le Guen, C.; Suaria, G.; Sherley, R. B.; Ryan, P. G.; Aliani, S.; Boehme, L.; Brierley, A. S. Microplastic study reveals the presence of natural and synthetic fibres in the diet of King Penguins (Aptenodytes patagonicus) foraging from South Georgia. **Environment international**, 134, 105303, 2020. https://doi.org/10.1016/j.envint.2019.105303

Leslie, H. A.; Van Velzen, M. J.; Brandsma, S. H.; Vethaak, A. D.; Garcia-Vallejo, J. J.; Lamoree, M. H. Discovery and quantification of plastic particle pollution in human blood. **Environment international**, 163, 107199, 2022. https://doi.org/10.1016/j.envint.2022.107199

Liebezeit, G.; Liebezeit, E. Non-pollen particulates in honey and sugar. **Food Additives & Contaminants: Part A**, 30(12), 2136-2140, 2013. https://doi.org/10.1080/19440049.2013.843025

Liebezeit, G.; Liebezeit, E. Synthetic particles as contaminants in German beers. **Food Additives & Contaminants: Part A**, 31(9), 1574-1578, 2014. https://doi.org/10.1080/19440049.2014.945099

Lithner, D.; Larsson, Å.; Dave, G. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. **Science of the total environment**, 409(18), 3309-3324, 2011. https://doi.org/10.1016/j.scitotenv.2011.04.038

Lusher, A. L.; Bråte, I. L. N.; Munno, K.; Hurley, R. R.; Welden, N. A. Is it or isn't it: the importance of visual classification in microplastic characterization. **Applied spectroscopy**, 74(9), 1139-1153, 2020. https://doi.org/10.1177/0003702820930733

Ma, C.; Ramachandraiah, K.; Jiang, G. Micro and nano plastics: contaminants in beverages and prevention strategies. **Frontiers in Sustainable Food Systems**, v. 8: 1491290. https://doi.org/10.3389/fsufs.2024.1491290

Makhdoumi, P.; Amin, A. A.; Karimi, H.; Pirsaheb, M.; Kim, H.; Hossini, H. Occurrence of microplastic particles in the most popular Iranian bottled mineral water brands and an assessment of human exposure. **Journal of water process engineering**, 39, 101708, 2021. https://doi.org/10.1016/j.jwpe.2020.101708

Mason, S. A.; Welch, V. G.; Neratko, J. Synthetic polymer contamination in bottled water. *Frontiers in chemistry*, 6, 389699, 2018. https://doi.org/10.3389/fchem.2018.00407

Massardo, S.; Verzola, D.; Alberti, S.; Caboni, C.; Santostefano, M.; Verrina, E. E.; ... Artini, C. MicroRaman spectroscopy detects the presence of microplastics in human urine and kidney tissue. **Environment international**, 184, 108444, 2024. https://doi.org/10.1016/j.envint.2024.108444

Mateos-Cárdenas, A.; O'Halloran, J.; van Pelt, F. N.; Jansen, M. A. Beyond plastic microbeads–short-term feeding of cellulose and polyester microfibers to the freshwater amphipod Gammarus duebeni. **Science of the Total Environment**, 753, 141859, 2021. https://doi.org/10.1016/j.scitotenv.2020.141859

Mercy, F. T.; Alam, A. R. Assessment of microplastic contamination in shrimps from the Bay of Bengal and associated human health risk. **Marine Pollution Bulletin**, 201, 116185, 2024. https://doi.org/10.1016/j.marpolbul.2024.116185

Miller, E.; Sedlak, M.; Lin, D.; Box, C.; Holleman, C.; Rochman, C. M.; Sutton, R. Recommended best practices for collecting, analyzing, and reporting microplastics in environmental media: Lessons learned from comprehensive monitoring of San Francisco Bay. **Journal of hazardous materials**, 409, 124770, 2021. https://doi.org/10.1016/j.jhazmat.2020.124770

Montano, L., Giorgini, E., Notarstefano, V., Notari, T., Ricciardi, M., Piscopo, M., & Motta, O. (2023). Raman Microspectroscopy evidence of microplastics in human semen. *Science of the Total Environment*, 901, 165922. https://doi.org/10.1016/j.scitotenv.2023.165922

Napper, I. E.; Thompson, R. C. Plastic debris in the marine environment: history and future challenges. **Global Challenges**, 4(6), 1900081, 2020. https://doi.org/10.1002/gch2.201900081

Nocoń, W.; Moraczewska-Majkut, K.; Wiśniowska, E. Microplastics in bottled water and bottled soft drinks. **Desalination and Water Treatment**, 312, 64-69, 2023. https://doi.org/10.5004/dwt.2023.29946

Nunes, L. S.; Silva, A. G.; Espínola, L. A.; Blettler, M. C.; Simões, N. R. Intake of microplastics by commercial fish: a Bayesian approach. **Environmental Monitoring and Assessment**, 193(7), 402, 2021. https://doi.org/10.1007/s10661-021-09156-1

Oßmann, B. E.; Sarau, G.; Holtmannspötter, H.; Pischetsrieder, M.; Christiansen, S. H.; Dicke, W. Small-sized microplastics and pigmented particles in bottled mineral water. **Water research**, 141, 307-316, (2018). https://doi.org/10.1016/j.watres.2018.05.027

Olivatto, G. P.; Ando, R. A.; Fernandes, R. F.; Lourenço, A. L. A.; de Souza, A. J.; Tornisielo, V. L. Temporal and spatial distribution of microplastics in the freshwater Atibaia river basin, Campinas-SP, Brazil. **Heliyon**, 10(23), 2024. https://doi.org/10.1016/j.heliyon.2024.e40622

Oliveira, C. W. L.; Oliveira, L. F. A. M.; Garcia, J.; Weingrill, R. B.; Urschitz, J.; Souza, S. T.; Fonseca, E. J. S.; Ospina-Prieto, S.; Borbely, A. First evidence of microplastic accumulation in placentas and umbilical cords from pregnancies in Brazil. *Annals of the* **Brazilian Academy of Sciences**, 97, 3, 2025. https://doi.org/10.1590/0001-3765202520241298

Patidar, K.; Alluhayb, A. H.; Younis, A. M.; Dumka, U. C.; Ambade, B. Investigation of microplastic contamination in the gastrointestinal tract of fish: A comparative study of various freshwater species. **Physics and Chemistry of the Earth, Parts A/B/C**, 136, 103760, 2024. https://doi.org/10.1016/j.pce.2024.103760

Plastics Europe. The Circular Economy for Plastics. A European Analysis, 2024. https://plasticseurope.org/knowledge-hub/the-circular-economy-for-plastics-a-european-analysis-2024/

Prata, J. C.; Reis, V.; da Costa, J. P.; Mouneyrac, C.; Duarte, A. C.; Rocha-Santos, T. Contamination issues as a challenge in quality control and quality assurance in microplastics analytics. **Journal of Hazardous Materials**, 403, 123660, 2021. https://doi.org/10.1016/j.jhazmat.2020.123660

Pratesi, C. B.; AL Santos Almeida, M. A.; Cutrim Paz, G. S.; Ramos Teotonio, M. H.; Gandolfi, L.; Pratesi, R.; ... Zandonadi, R. P. Presence and quantification of microplastic in urban tap water: a pre-screening in Brasilia, Brazil. **Sustainability**, 13(11), 6404, 2021. https://doi.org/10.3390/su13116404

Praveena, S. M.; Ariffin, N. I. S.; Nafisyah, A. L. Microplastics in Malaysian bottled water brands: Occurrence and potential human exposure. **Environmental Pollution**, 315, 120494, 2022. https://doi.org/10.1016/j.envpol.2022.120494

Rabelo, E. F.; Oliveira, R. C. M.; Freitas, J. C. do N.; Silva, M. L. C.; Brabo, L.; Ziveri, P.; Grelaud, M.; Bessa, F.; Sobral, P.; Guilherme, A.; Giarrizzo, T.; Soares, M. O. Microplastic pollution in bivalve species from tropical mangrove habitats. **Regional Studies in Marine Science**, 87, 104227, 2025. https://doi.org/10.1016/j.rsma.2025.104227

Ragusa, A.; Notarstefano, V.; Svelato, A.; Belloni, A.; Gioacchini, G.; Blondeel, C.; ... Giorgini, E. Raman microspectroscopy detection and characterisation of microplastics in human breastmilk. **Polymers**, 14(13), 2700, 2022. https://doi.org/10.3390/polym14132700

Ramaremisa, G.; Erasmus, R. M.; Tutu, H.; Saad, D. Occurrence and characteristics of microplastics in South African beverages. **Environmental Pollution**, 365, 125388, 2025. https://doi.org/10.1016/j.envpol.2024.125388

Ribeiro, V. V.; Casado-Coy, N.; Rangel, D. F.; Sanz-Lazaro, C.; Castro, Í. B. Microplastic in bivalves of an urbanized Brazilian estuary: Human modification, population density and vegetation influence. **Journal of Hazardous Materials**, 482, 136546, 2025. https://doi.org/10.1016/j.jhazmat.2024.136546

Salgado, P. R.; Di Giorgio, L.; Musso, Y. S.; Mauri, A. N. Recent developments in smart food packaging focused on biobased and biodegradable polymers. **Frontiers in Sustainable Food Systems**, 5, 630393, 2021. https://doi.org/10.3389/fsufs.2021.630393

Samandra, S.; Mescall, O. J.; Plaisted, K.; Symons, B.; Xie, S.; Ellis, A. V.; Clarke, B. O. Assessing exposure of the Australian population to microplastics through bottled water consumption. **Science of the Total Environment**, 837, 155329, 2022. https://doi.org/10.1016/j.scitotenv.2022.155329

Sangkham, S.; Faikhaw, O.; Munkong, N.; Sakunkoo, P.; Arunlertaree, C.; Chavali, M.; Mousazadeh, M.; Tiwari, A. A review on microplastics and nanoplastics in the environment: Their occurrence, exposure routes, toxic studies, and potential effcts on human health. **Marine Pollution Bulletin**, 181, 113832, 2022. https://doi.org/10.1016/j.marpolbul.2022.113832

Schuab, J. M.; Dalbó, G. Z.; Berquó, S. P. P.; Fernandes, B. L.; Menezes, K. M.; Alves, M. M.; Andrade, E.; Souza, R.; Marins, A. A. L.; Ocaris, E. R. Y.; da Costa, M. B. Evaluation of Microplastic Contamination in Table Sugar: What Does Sugar Have Besides Its Sweetness?. . **Earth: Environmental Sustainability**, *1*(1), 2025. https://media.sciltp.com/articles/2508001103/2508001103.pdf

Schuab, J. M.; de Paula, M. S.; Ocaris, E. R. Y.; Milagres, M. R.; Motta, D. G.; da Costa, M. B. First record of microplastic in the Brazilian sea hare Aplysia brasiliana Rang, 1828 (Mollusca: Aplysiidae). **Science of The Total Environment**, 895, 165156, 2023. https://doi.org/10.1016/j.scitotenv.2023.165156

Schwabl, P.; Köppel, S.; Königshofer, P.; Bucsics, T.; Trauner, M.; Reiberger, T.; Liebmann, B. Detection of various microplastics in human stool: a prospective case series. **Annals of internal medicine**, 171(7), 453-457, 2019. https://doi.org/10.7326/M19-0618

Schymanski, D.; Goldbeck, C.; Humpf, H. U.; Fürst, P. Analysis of microplastics in water by micro-Raman spectroscopy: Release of plastic particles from different packaging into mineral water. **Water research**, 129, 154-162, 2018. https://doi.org/10.1016/j.watres.2017.11.011

Senathirajah, K.; Attwood, S.; Bhagwat, G.; Carbery, M.; Wilson, S.; Palanisami, T. Estimation of the mass of microplastics ingested–A pivotal first step towards human health risk assessment. **Journal of hazardous materials**, 404, 124004, 2021. https://doi.org/10.1016/j.jhazmat.2020.124004

Sewwandi, M.; Wijesekara, H.; Rajapaksha, A. U.; Soysa, S.; Vithanage, M. Microplastics and plastics-associated contaminants in food and beverages; Global trends, concentrations, and human exposure. **Environmental Pollution**, 317, 120747, 2023. https://doi.org/10.1016/j.envpol.2022.120747

Serviço Geológico do Brasil (SGB). Mercado de água mineral brasileiro. Ministério de Minas e Energia. Retrieved August 15, 2025, from https://www.sgb.gov.br/mercado-de-agua-mineral-brasileiro

Shruti, V. C.; Pérez-Guevara, F.; Elizalde-Martínez, I.; Kutralam-Muniasamy, G. First study of its kind on the microplastic contamination of soft drinks, cold tea and energy drinks-Future research and environmental considerations. **Science of the total environment**, 726, 138580, 2020. https://doi.org/10.1016/j.scitotenv.2020.138580

Socas-Hernández, C.; Miralles, P.; González-Sálamo, J.; Hernández-Borges, J.; Coscolla, C. Assessment of anthropogenic particles content in commercial beverages. **Food Chemistry**, 447, 139002, 2024. https://doi.org/10.1016/j.foodchem.2024.139002

Sobhani, Z.; Lei, Y.; Tang, Y.; Wu, L.; Zhang, X.; Naidu, R.; ... Fang, C. Microplastics generated when opening plastic packaging. **Scientific reports**, 10(1), 4841, 2020. https://doi.org/10.1038/s41598-020-61146-4

Socas-Hernández, C.; Miralles, P.; González-Sálamo, J.; Hernández-Borges, J.; Coscolla, C. Assessment of anthropogenic particles content in commercial beverages. **Food Chemistry**, 447, 139002, 2024. https://doi.org/10.1016/j.foodchem.2024.139002

Suteja, Y.; Dirgayusa, I. G. N. P.; Purnama, S, G.; Purwiyanto, A. I. S. From sea to table: Assessing microplastic contamination in local and non-local salt in Bali, Indonesia. **Chemosphere**, 374, 144192, 2025. https://doi.org/10.1016/j.chemosphere.2025.144192

Ta, A. T.; Babel, S.; Wang, L. P. Prevalence and characteristics of microplastic contamination in soft drinks and potential consumer exposure. **Journal of Environmental Management**, 474, 123810, 2025. https://doi.org/10.1016/j.jenvman.2024.123810

Ta, A. T.; Promchan, N. Microplastics in wastewater from developing countries: A comprehensive review and methodology suggestions. **TRAC Trends in Analytical Chemistry**, *171*, 117537, 2024. https://doi.org/10.1016/j.trac.2024.117537

Tang, K. H. D.; Li, R., Li, Z.; Wang, D. Health risk of human exposure to microplastics: a review. **Environmental Chemistry Letters**, 22(3), 1155-1183, 2024. https://doi.org/10.1007/s10311-024-01727-1

Tang, S.; Lin, L.; Wang, X.; Feng, A.; Yu, A. Pb (II) uptake onto nylon microplastics: interaction mechanism and adsorption performance. **Journal of hazardous materials**, 386, 121960, 2020. https://doi.org/10.1016/j.jhazmat.2019.121960

Teuten, E. L.; Saquing, J. M.; Knappe, D. R.; Barlaz, M. A.; Jonsson, S.; Björn, A.; .. Takada, H. Transport and release of chemicals from plastics to the environment and to wildlife. **Philosophical transactions of the royal society B: biological sciences**, 364(1526), 2027-2045, 2009. https://doi.org/10.1098/rstb.2008.0284

Thompson, R. C.; Olsen, Y.; Mitchell, R. P.; Davis, A.; Rowland, S. J.; John, A. W.; ... Russell, A. E. Lost at sea: where is all the plastic?. **Science**, 304(5672), 838-838, 2004. DOI: 10.1126/science.1094559

Vasudeva, M.; Warrier, A. K.; Kartha, V. B; Unnikrishnan, V. K. Advances in microplastic characterization: Spectroscopic techniques and heavy metal adsorption insights. **TrAC Trends in Analytical Chemistry**, 183, 118111, 2025. https://doi.org/10.1016/j.trac.2024.118111

Visentin, E.; Manuelian, C. L.; Niero, G.; Benetti, F.; Perini, A.; Zanella, M.; ... De Marchi, M. Characterization of microplastics in skim-milk powders. **Journal of Dairy Science**, 107(8), 5393-5401, 2024. https://doi.org/10.3168/jds.2023-24373

Visentin, E.; Niero, G.; Benetti, F.; O'Donnell, C.; De Marchi, M. Assessing microplastic contamination in milk and dairy products. **npj Science of Food**, 9, 135, 2025. https://doi.org/10.1038/s41538-025-00506-8

Wang, C.; Zhao, J.; Xing, B. Environmental source, fate, and toxicity of microplastics. **Journal of hazardous materials**, 407, 124357, 2021. https://doi.org/10.1016/j.jhazmat.2020.124357

Winkler, A.; Santo, N.; Ortenzi, M. A.; Bolzoni, E.; Bacchetta, R.; Tremolada, P. Does mechanical stress cause microplastic release from plastic water bottles?. **Water research**, 166, 115082, 2019. https://doi.org/10.1016/j.watres.2019.115082

Yang, D.; Shi, H.; Li, L.; Li, J.; Jabeen, K.; Kolandhasamy, P. Microplastic pollution in table salts from China. **Environmental science & technology**, 49(22), 13622-13627, 2015. https://doi.org/10.1021/acs.est.5b03163

Yang, X.; Man, Y. B.; Wong, M. H.; Owen, R. B.; Chow, K. L. Environmental health impacts of microplastics exposure on structural organization levels in the human body. **Science of the Total Environment**, 825, 154025, 2022. https://doi.org/10.1016/j.scitotenv.2022.154025

Zanetti, D. G.; Gomes, L. E. de O.; Bom, F. C.; Sá, F. Microplastic in Brazilian sediments: Systematic review of coastal and marine areas for a national monitoring program. **Regional Studies in Marine Science**, 91, 104590, 2025. https://doi.org/10.1016/j.rsma.2025.104590

Zhu, L.; Kang, Y.; Ma, M.; Wu, Z.; Zhang, L.; Hu, R.; ... An, L. Tissue accumulation of microplastics and potential health risks in human. **Science of the Total Environment**, 915, 170004, 2024. https://doi.org/10.1016/j.scitotenv.2024.170004