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Research article



Prevalence of microplastics in commercially sold soft drinks and human risk assessment

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ABSTRACT

Due to the increasing global plastic production and use in recent years, the amount of microplastic (MP) accumulating in the environment has also increased. This microplastic pollution potential has been documented mostly in studies of the sea or seafood. The presence of microplastics in terrestrial foods has therefore attracted less attention, despite the potential for future major environmental risks. Some of these researches are related to bottled water, tap water, honey, table salt, milk, and soft drinks. However, the presence of microplastics in soft drinks has not yet been evaluated in the European continent, including Türkiye. Hence, the current study focused on the presence and distribution of microplastics in ten soft drink brands in Türkiye since the water utilized in the bottling process of soft drinks originates from different water supply sources. Using FTIR stereoscopy and stereomicroscope examination, MPs were detected in all of these brands. According to the microplastic contamination factor (MPCF) classification, 80% of the soft drink samples indicated a high level of contamination with microplastics. The study's findings showed that each liter of consumed soft drinks exposes people to about nine microplastic particles, which is a moderate dose when compared to exposure levels in earlier research. It has been determined that bottle-production processes and the substrates used for food production may be the main sources of these microplastics. The chemical components of these microplastic polymers were polyamide (PA), polyethylene terephthalate (PET) and polyethylene (PE), and fibers were the dominant shape. Compared to adults, children were subjected to higher microplastic loads. The study's preliminary data on MP contamination of soft drinks may be useful for further evaluating the risks exposure to microplastics poses to human health.

1. Introduction

Plastics are frequently used in daily life, thanks to their use for many different purposes and their advantages (low cost, durability, workability, etc.). Accordingly, it was reported that worldwide plastic production in 2020 exceeded 367 million tons (PlasticsEurope, 2021), and it is predicted that by 2050, approximately three times as much plastic would accumulate in the environment (Geyer et al., 2017). However, both the production process and the waste generated after the consumption of plastics pose a severe risk to the environment and public health (Vitali et al., 2022). These plastic wastes spread over large areas with the influence of environmental factors and form microplastics (MPs) by breaking into smaller pieces over time. Polymers of a size between 1 μm and 5 mm are referred to as MPs (Frias and Nash, 2019), and categorized as primary or secondary microplastics based on their sources (Yao et al., 2020). The former are small parts for both commercial and home usage and contain numerous plastic components (e.g. fiber, pellet, etc.) used in the agricultural, cosmetic, and pharmaceutical industries (Fendall and Sewell, 2009; Jeyavani et al., 2021). The latter is the outcome of larger plastic parts breaking down into smaller ones (e.g. fragments) (Guzzetti et al., 2018).

The ultimate sink for plastic waste is the marine ecosystem, which receives the vast majority of plastic waste and its residues (Sönmez et al., 2023). The majority of these microplastics are known to have entered this ecosystem through human causes (Guo et al., 2022). This is supported by the fact that several MPs, including synthetic polymers from diverse anthropogenic sources, have been detected in the air (Gasperi et al., 2019). Although the first reports of MP pollution are related to the marine environment (Moore et al., 2001; Mato et al., 2001; Ryan et al., 2009; Jambeck et al., 2015), current research provides evidence that freshwater resources are also exposed to this pollution (Mani et al., 2015; Koelmans et al., 2019; Tatlı et al., 2022). Additionally, they reach freshwater ecosystems through runoff, wastewater discharge, combined sewage floods, deteriorated plastic contaminants, and climatic procedures (Li et al., 2018). Numerous ecotoxicological investigations have shown that certain species may experience reproductive issues,

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oxidative stress, organ degeneration, overall deterioration, and consequent death as a consequence of ingestion of microplastics (Wang et al., 2019; Lu et al., 2019; Burgos-Aceves et al., 2021).

Presence of microplastics in the human dietary chain has been well-documented in the last decade (Jin et al., 2021). For instance, drinking water (Schymanski et al., 2018; Mangala et al., 2022), milk (Diaz-Basantes et al., 2020; Kutralam-Muniasamy et al., 2020), honey (Diaz-Basantes et al., 2020), mineral waters (Makhdoumi et al., 2021; Altunışık, 2023), and soft drinks (Shruti et al., 2020) have been found to contain microplastics. A growing number of reports of microplastic pollution in water and other drinks, along with the relatively high consumption of soft drinks, have drawn the public's focus to the issue of microplastics (Schymanski et al., 2018; Mason et al., 2018; Diaz-Basantes et al., 2020; Mangala et al., 2022).

Drinks that are designed for human consumption can be broadly categorized as either alcoholic or non-alcoholic. Soft drinks are widely used non-alcoholic beverages that are popular all over the world. Republic of Türkiye Ministry of Agriculture and Forestry, General Directorate of Water Management is in charge of safety and monitoring drinking water quality and the purity of the tap water used to make packaged beverages is under the scrutiny of the appropriate government authorities. Although Pehlivan's (2007) research reported that bottled water in Türkiye complies with the WHO: World Health Organization guidelines and the Ministry of Agriculture and Forestry (Türkiye), there is no data on the appropriateness of bottled beverages. In addition, the long-term increase in the use of plastic raises our doubts about food safety. Considering the presence and abundance of microplastics in freshwater systems, the water source may be a significant source of contamination in commercially sold drinks (Kosuth et al., 2018; Shen et al., 2021; Mangala et al., 2022). Treatment and purification processes of water used for beverages are other possible sources of MPs in terms of food safety (Li et al., 2023). Furthermore, microplastics can form as a result of friction between the cap and the bottle, especially when opening and closing the cap (Winkler et al., 2019; Sobhani et al., 2020; Makhdoumi et al., 2021). Another important potential route is that microplastics in beverages can come from bottle production and filling processes (Zhou et al., 2021; Sewwandi et al., 2023). Therefore, understanding the possible threats to human health from microplastic contamination is essential given the rising trend of soft drink consumption in Türkiye.

This study was encouraged because there is insufficient data in the literature on soft drinks and regulatory authorities demand more information (Horton et al., 2017). In this context, the main purposes of this study are to (1) investigate the prevalence of microplastics; (2) identify the characteristics (type, shape, size, and color of polymers) of microplastics in ten soft drink brands in Türkiye; (3) assess human health risk for both adult and child groups by estimating daily intake (EDI) and estimated annual intake (EAI); (4) compare the prevalence of microplastics in the selected commercial drinks from Türkiye to previous research that has been done.

2. Materials and methods

2.1. Collection and selection of samples

A preliminary survey was first undertaken to determine the top-selling soft drinks brands at big supermarkets and retail grocery stores in the cities of Rize and Trabzon. On the basis of this survey, ten soft drink brands (n = 30) in single-use packages commonly sold in the region were selected. Three replicates of these brands were processed for a particular sample set. Hence, a total of 30 soft drinks, 15 in polyethylene terephthalate (PET) bottles and 15 in Tetra Pak packages in 1 L volumes, were purchased from Rize, Türkiye. The shelf life of all samples was between June and December of 2023, which will not affect the test results in terms of bottle durability. To preserve brand name anonymity, all ten soft drink brands were labeled from A to J, stored at room temperature, and investigated within ten days at the latest.

2.2. Measures taken to prevent contamination

To prevent possible MP cross-contamination of the soft drink samples used in this study, the processes were conducted under a closed fume hood and nitrile gloves were used. In addition, experimenters wore cotton laboratory coats at all stages of the experiment. Whole samples were purified 75% ethyl alcohol. After each use, the equipment was washed with distilled water and wrapped with metal foil. To take into consideration background contamination, deionized water was also leached and used as a control sample.

2.3. Extraction of MPs

Standard filtration techniques were used to determine the prevalence of MPs in the beverage samples. To summarize, the beverage was filtered by a vacuum pump using a filter paper with a pore size: 0.45 μm. To hinder the external dirtiness of samples, a watch glass was placed on top of the filtration apparatus. Following filtering, the filter sheets were kept inside a distinct clean Petri dish, sealed, and kept in a dark room prior to identification and counting of the particles. Blank samples (the deionized water) underwent the same analysis as the samples of soft drinks.

2.4. Analytical method

All particles suspected of being MPs were examined with a stereomicroscope (Leica S6D) and then counted with a syringe needle and transferred to a new separate filter. Photographs of these particles were taken with a camera attached to the Leica EC3®. Particle lengths were determined using a web tool called ImageJ (http://imagej.nih.gov/ij/). According to their morphologies, potential MP particles were categorized as fragments, fibers, or films. These materials were evaluated and validated using the FT–IR (Fourier Transform–Infrared) spectroscopy. Each sample's spectrum was matched to an FTIR reference spectrum, and only those with more than 70% spectral similarity were defined as microplastic (Tatlı et al., 2022; Altunışık, 2023).

2.5. Calculating the microplastic contamination factor and the pollution load index

The microplastic contamination factor (MPCF) and pollution load index (MPLI) in soft drinks were estimated as indicated by Kabir et al. (2021). The MPCF explains the amount of MP pollution in the examined soft drinks in relation to background levels. MPCF were divided into four groups: low contamination (MPCF<1), moderately contaminated (MPCF range: 1–3); considerably contaminated (MPCF range: 3–6), and very highly contaminated (MPCF greater than 6) (Ibeto et al. (2021). The MPCF and MPLI were calculated using Equations (1) and (2), respectively. Where MP_a is the number of MPs in sample a and MP_m is the smallest baseline amount determined from the fewest MPs prevalence indicated by Shruti et al. (2020). Because the related study has been undertaken in comparable environments and with equivalent analytical approaches.

$$\mathrm{MPCF} = \frac{MP_a}{MP_m} \tag{1}$$

$$\mathrm{MPLI} = \left(\mathrm{MPCF_1 \, x \, MPCF_2 \, x \, MPCF_3 \ldots\ldots\ldots\ldots \, MPCF_{10}}\right)^{1/10} \tag{2}$$

2.6. Risk estimations

To calculate the *Estimated daily intake* (EDI) of microplastic concentrations in soft drinks, Equation (3) was used.

$$\mathrm{EDI} = (\mathrm{Cr} \times \mathrm{IR}) \ / \mathrm{bw/day} \tag{3}$$

Equation (4) was utilized to compute *Estimated annual intake* (EAI)

$$EAI = IR \times Cr/bw/year \quad (4)$$

In these equations, Cr refers to MPs concentration (particles/L); IR represents rate of the ingestion, which was assumed to be consumption of soft drinks in Türkiye (natural water: 0.03 L/day-adults and 0.02 L/day-children; (TBSASağlık Bakanlığı Araştırmaları Genel Müdürlüğü, 2019); and the bw is the body weigth assuming that adults weigh 70 kg, whereas children weigh 16 kg (Arena et al., 2015).

2.7. Data analysis

To assess the homogeneity and normality of variances, Levene and Shapiro–Wilks tests were used, respectively. Then, a one-sample *t*-test was conducted to see whether there were any statistically significant variations between the amounts of microplastic particles in soft drink samples and control samples. In addition, an independent sample *t*-test was utilized to understand whether the microplastic concentration of the soft drink brands differed according to the packaging material (PET or Tetra Pak). The statistical variances in the experimental data were assessed using SPSS 21.

3. Results and discussion

3.1. Occurrence and quantification of MPs

In the current study, pieces in the form of fragments (n = 1.60 ± 0.92) were present in blank samples. In accordance with the conclusions of Oβmann et al. (2018) and Mangala et al. (2022), they might have entered the deionized water system through the filter housing. On the other hand, the absence of fiber particles in blank samples during analysis indicates that laboratory contamination is avoided (Kosuth et al., 2018; Mangala et al., 2022).

Fig. 1 demonstrates the mean MP particles of ten soft drink brands after taking away equivalent background contaminants from the control samples. MPs were found in all samples of soft drinks, which ranged in concentration from 5 to 15 particles/L (mean: 8.9 particles/L) (Table 1). In addition, the average number of MPs in the soft drink samples and the blank samples varied significantly (one-sample *t*-test; $t = 7.137$, $df = 9$, $p < 0.01$). This result shows that microplastics may have been present in soft drink samples from a number of sources, including unfiltered water, packing, and/or bottling (Mangala et al., 2022; Schymanski et al., 2018).

The sample G (15 MP/L), which packaging bottles made of PET, had the greatest level of microplastics. The second-highest amount of MPs was also identified in a PET-packaged bottle (Sample F; 12 MP/L). The fact that G and F brands, which have higher microplastic concentrations than others, use tap water obtained by conventional drinking water treatment in beverage production, maybe a possible reason for this difference. On the other hand, the samples containing the lowest microplastic concentration belonged to brands A and B in the Tetra Pak packaged soft drinks. To understand whether the microplastic concentration of the brands differs between packaging materials, although there is an average higher Mp concentration in the brands in PET bottles, this distinction is not statistically noteworthy (*t*-test; $t = -1.762$, $df = 8$, $p = 0.116$). It is well-documented that bottle caps and packaging materials are the principal origins of MPs in beverages (Makhdoumi et al., 2021; Mangala et al., 2022; Schymanski et al., 2018). For instance, PET, the material specially used to produce single-serve water and soft drink bottles, does break down over time and might potentially contaminate water supplies with microplastics. Additionally, it is believed that any tension placed on recyclable PET bottles can cause particles to be released, which could affect the entry of large volumes of fragments into drinks (Schymanski et al., 2018; Sewwandi et al., 2023). Although Tetra Pak is a shelf-stable carton with plastic and aluminum content, it contains polymers similar to PET. Therefore, the relatively low number of microplastics in the Tetra Pak is probably due to the difference in the processing of such packaging.

This study is one of the limited investigations on microplastic contamination in soft drinks. In the first of these, the researchers detected a total of 40 microplastics (mean: 7 ± 3.21), which corresponds to two microplastics per sample in the 19 bottles they analyzed in Mexico (Shruti et al., 2020). In another study conducted in Ecuador, the average number of microplastic particles found by researchers in 1 L of soft drinks was 32 (Diaz-Basantes et al., 2020). Compared to the previous studies, these results revealed that the mean MP concentrations found in this study was higher than in Mexico and lower than in Ecuador. In this study, we included mineral waters in addition to soft drinks for comparison of microplastic occurrence (see Table 1). Analyzing mineral waters in Germany, Schymanski et al. (2018) reported that the amount of microplastic detected in returnable bottles (118 particles/L) was higher than that in disposable bottles (14 particles/L). In addition, another study from the same country confirmed that the amount of MP in returnable bottles (4889 particles/L) is higher than in disposable bottles (2649 particles/L) (Oβmann et al., 2018). Their findings indicate that mineral water in bottles has the greatest MP

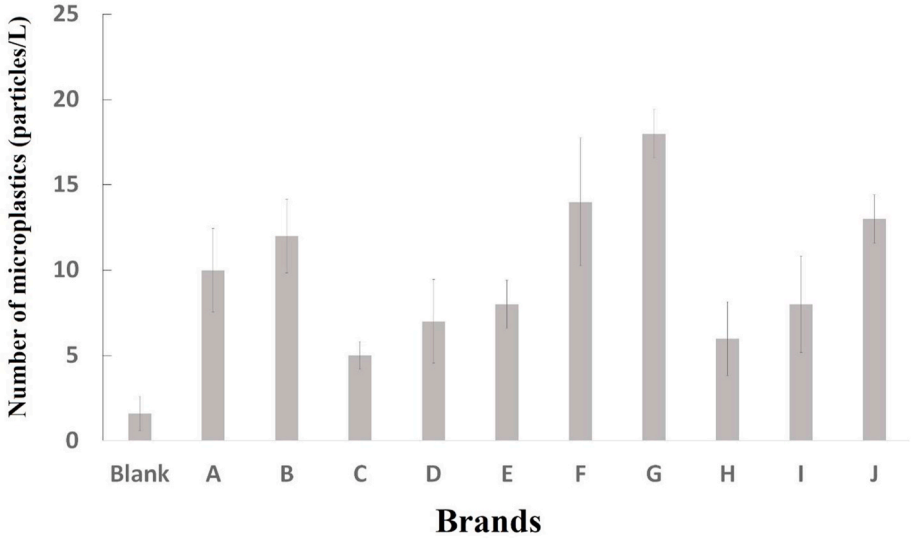


Fig. 1. The quantity of microplastics found in samples tested from different soft drink brands in Türkiye.

Table 1
Comparison of characteristics of soft drinks and mineral waters contaminated with microplastics.

Country	Type of beverages and packaging material	Range (microplastics particles/L; average ± SD)	Polymer types	Microplastics size	Shapes	Colors	References
Mexico	Soft drinks: PET plastic bottles	7 ± 3.21	PA, BP, PEA	100–3000 μm	fiber	blue, red, brown	Shruti et al., (2020)
Ecuador	Soft drinks: PET bottle or Tetra Pak	32	PP, PE, PAAm	5.47–2224.25 μm	fiber, fragment	red, green, violet, yellow, and blue	Diaz-Basantes et al., (2020)
Iran	Mineral water: PET plastic bottles	8.5 ± 10.2	PET, PS, PE	1280–4.200 μm	fragment, fiber	transparent, black	Makhdoumi et al., (2021)
Germany	Mineral water:	14 ± 14	PET, PE, PS and PP	5–20 μm (80%)	fragment	–	Schymanski et al., (2018)
Germany	Mineral water: PET and glass bottles	2649 ± 2857 P/L (PET bottles) and 6292 ± 10,521 P/L (glass bottles)	PET, PE, PP, Styrene-Butadiene- Copolymer, and others	≤1.5–5 μm (80%)	fragment	blue, yellow, violet, red	Oβmann et al. (2018)
Türkiye	Soft drinks: PET plastic bottles and Tetra Pak	8.9 ± 2.95	PA, PET, PE	10–1000 μm	Fragment, fiber, film	Transparent, blue, grey, green, yellow	This study

concentrations.

Another important factor in determining the occurrence of MPs is the source of water used to prepare the various foods. If water is the primary component or the foods are prepared with industrial service water from each nation's municipal source, the treatment processes typically cannot remove microparticles from the food. The amount of filtration used on the meals that have been studied so far is insufficient to get rid of microplastics (Diaz-Basantes et al., 2020). There are many possible scenarios for the source of microplastics in foods and beverages. For example, Geyer et al. (2017) reported that packaging materials can be an important source of MP in processed foods, Sobhani et al. (2020), on the other hand, found that MPs can be released inside during the plastic packaging opening process. Food additives, food packaging, and receptacles made of plastic, like bottles, glasses, bags, and polluted surface water are reported to be some of the sources that can contaminate food and drinks with microplastics (Sewwandi et al., 2023). Besides, microplastics from worker overalls and fabrics, machine components, or atmospheric microplastics have been reported to contaminate food during production (Liebezeit and Liebezeit, 2013). Another potential pathway for the contamination of foods and drinks is the UV-induced deterioration of packaging materials (Zuccarello et al., 2019; Sewwandi et al., 2023). During manufacturing and processing, MPs could inadvertently be added. Additionally, due to the physical or environmental stress placed on the container during storage, transport, and use, they might be released from the plastic packaging and bottle caps (Lin et al., 2022). However, the occurrence of microplastics in freshwater environments is one of the main problems causing the spread of food contamination (Sewwandi et al., 2023; Pham et al., 2023). In general, the beverage industry uses vast amounts of fresh water; 1 L of soft drink requires 3–4 L of freshwater (Grumezescu and Holban, 2018). Additionally, far more water is wasted in manufacturing and/or cleaning beverage containers than is actually packaged and distributed in the containers (Shruti et al., 2020). Therefore, it is hypothesized that using different water sources may be one of the main causes of microplastic pollution in beverages. Sewage sludge is also detected as one of the main sources of microplastics in agricultural lands (Mahon et al., 2017; Piehl et al., 2018). The beverage bottling sector in this context gets its water from a number of sources, including groundwater, surface water, public water mains, and stormwater. The results of Kosuth et al. (2018), in which the authors promoted using local waters for the manufacturing of beverages in the United States, provide strong support for it. Although it is difficult to distinguish more specifically the sources of microplastics, it is assumed that the bottle production processes and substrates used for food production may be the main sources, based on qualitative data (i.e. chemical characterization).

3.2. MPs qualification

Three different kinds of micropolymers comprising polyethyleneterephthalate (PET), polyethylene (PE), and polyamide (PA) ranging from 5 to 18 polymers per sample, were found in soft drink brands (Fig. 2). The following types of polymer were prevalent in these brands: PA (42%) > PET (34%) > PE (24%). Fig. 3 demonstrates FTIR spectra and stereomicroscope images of the microplastics in the soft drink samples in this study. Conformably, Shruti et al. (2020) reported that the most common type of MPs in soft drinks analyzed was PA. Other reported polymers in that study were PET and Acrylonitrile-butadiene-styrene (ABS). On the other hand, Diaz-Basantes et al. (2020) reported that polypropylene (PP) and polyacrylamide (PAM) type polymers are common in many foodstuffs (soft drinks, honey, milk, beer, etc.) they analyzed. Additionally, the two most common polymers in German packaged water were PET (84%) and PP (7%) (Schymanski et al., 2018). In addition to these two plastics (PP and PET), polystyrene (PS) was also found in mineral waters of Iran (Makhdoumi et al., 2021). Investigations in Germany and China turned up a more comprehensive array of MPs. For example, seven types of polymers including PET, PE, PA, PP, PC (Polycarbonate), PVC, and PS were found by Oβmann et al. (2018) in Germany. On the other hand, 11 different types of MPs were found in Chinese bottled mineral and natural waters (Zhou et al., 2021). According to all the research cited (Enfrin et al., 2020; Singh, 2021), the production of PET for bottles and PE for caps is the main factor that led to the rise of PET and PE in bottled water. Additionally, data on the origin of plastics in water revealed that mechanical characteristics and the manufacturing procedure had an influence on how plastics break down and spread out (Julienne et al., 2019).

MPs' size is particularly important since they might potentially produce negative effects on human health. The general size distribution of these polymers detected in the current study was indicated in Fig. 4. The average size of MPs was 214.03 (range: 27–1213) μm. 72% of MPs were shorter than 200 μm. The length range of 50–100 μm was the most common (31.0%). MPs less than 100 μm make up 49% of the total, while MPS larger than 100 μm make up 51%. The present study's findings are consistent with those of Shruti et al. (2020) in that the majority of soft drink particles varied in size from 100 to 1000 μm. In another study (Diaz-Basantes et al., 2020) on soft drinks, researchers reported the presence of very long fibers (eg. 2224.25 μm) as well as very small fragments (eg. 5.47 μm). On the other hand, approximately 40% of the MPs detected in China's drinking water were found to be between 25 and 100 μm in size (Zhou et al., 2021). Because the above-mentioned studies were studied with FTIR, five-micron or less-sized plastic particles are challenging to distinguish (Zuccarello et al., 2019).

More than half (60%) of the MP particles identified in this study were

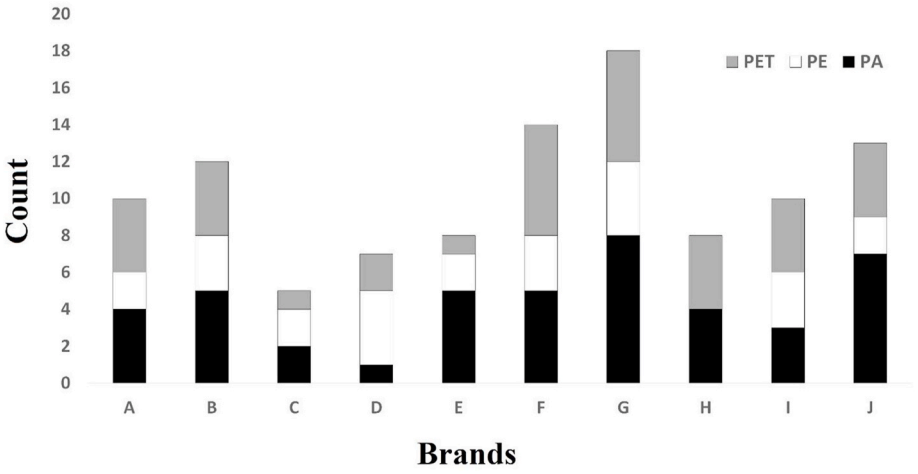


Fig. 2. Polymer types according to soft drink brands in Türkiye.

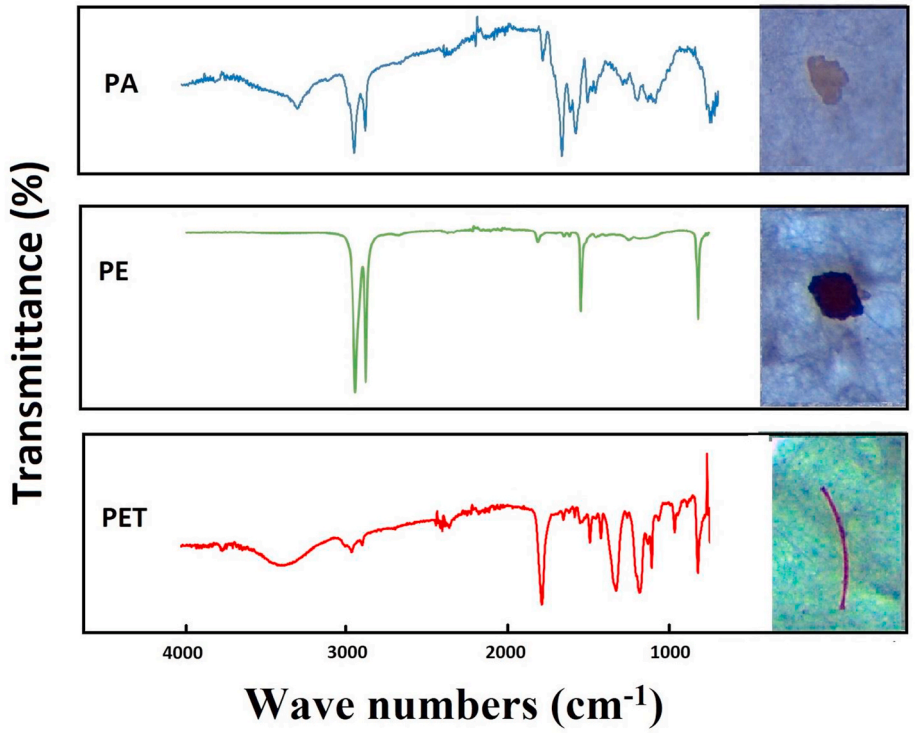


Fig. 3. Stereomicroscope photographs and FTIR spectrums of microplastics in the soft drinks in Türkiye. a: polyamide, b: polyethylene, c: polyethylene terephthalate. Fragments: a,b; fiber: c.

fiber in shape. The fiber was followed by fragments (34%) and films (6%), respectively. The fact that microplastics occur mostly in the form of fibers in the soft drink samples is similar to previous studies (Diaz-Basantes et al., 2020; Shruti et al., 2020). However, the most abundant type of microplastics detected in drinking water has been reported in many studies as fragments rather than fibers (Ibeto et al., 2021; Makhdoumi et al., 2021; Mason et al., 2018). Mason et al. (2018) hypothesized that the water bottling process' usage of industrial lubricants may be the origin of the particles. Despite this, Makhdoumi et al. (2021) claimed that because it was difficult to define other types, the fragment particles that they frequently saw in their experiments were likely categorized as belonging to the fragment class.

Five distinct shades of MPs were discovered, with the predominant being transparent (57%), followed by blue (28%), grey (12%), red (2%), and black (1%) (Fig. 5b). Similarly, five different colors (green, yellow, red, violet and blue) of particles were detected in the study of Diaz-Basantes et al. (2020), although they did not make an assessment of which of these colors was more prevalent. On the other hand, it was reported that there were fibril-shaped particles in three different colors—blue, red, and brown—with blue being the most prevalent in soft drinks in Mexico (Shruti et al., 2020). According to studies by Makhdoumi et al. (2021) and Shen et al. (2021), the most frequent colors of MP particles found in drinking water are transparent and black. Detection of particle color can be useful in determining the source of debris, as some investigations suggest that aquatic species absorb debris of certain colors better than others (Kosuth et al., 2018).

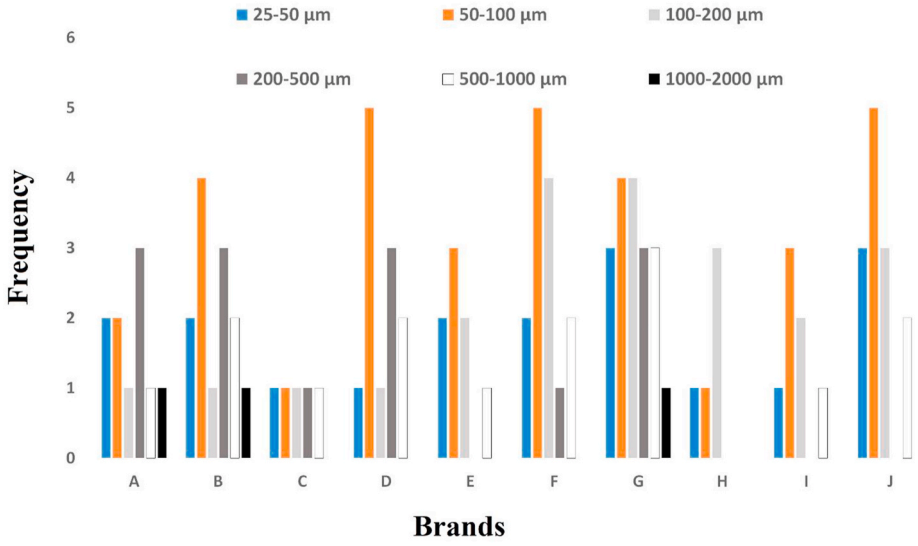


Fig. 4. The distribution of length of the microplastics in the soft drink brands from Türkiye.

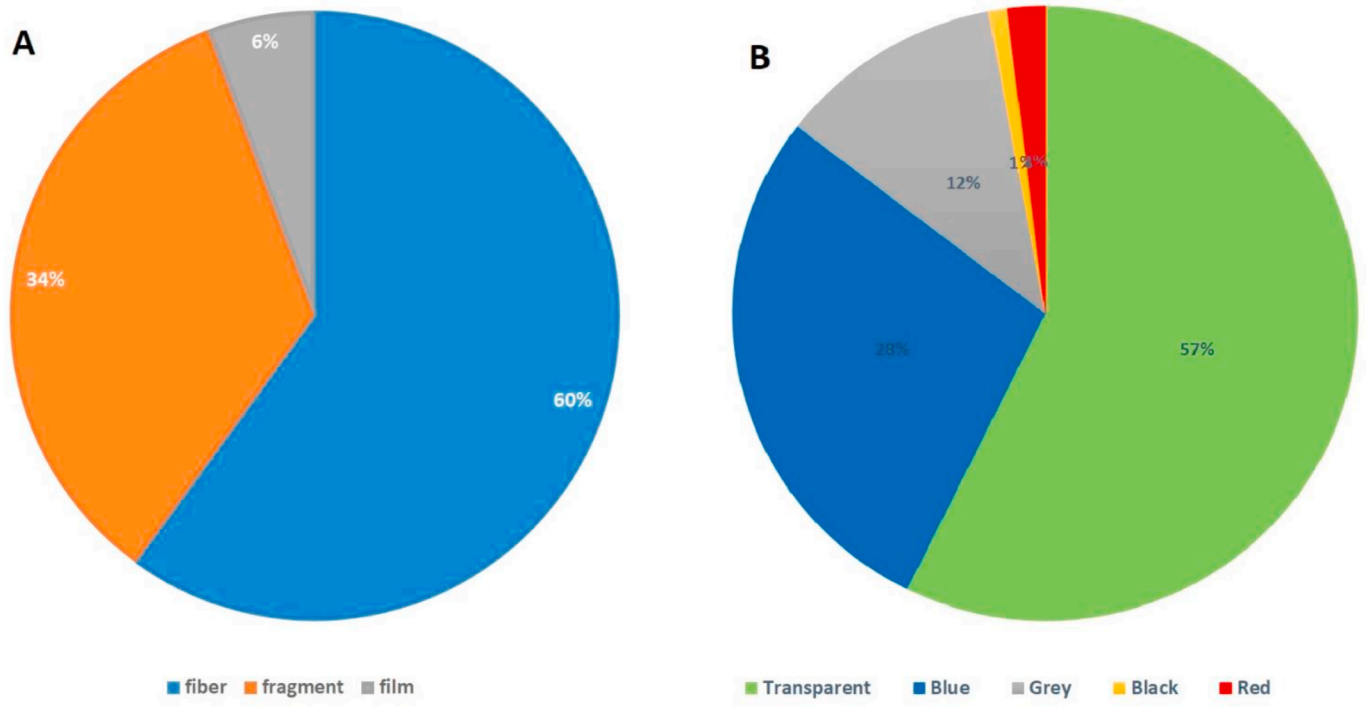


Fig. 5. Characterization of the microplastics in the soft drinks in Türkiye. A: composition shapes; B: colors.

3.3. Microplastic contamination factors (MPCF) and pollution load index (MPLI)

The MPCF ranged from 5 to 10 in the soft drinks packaged in Tetra Pak, and ranged from 7 to 15 in the soft drinks packed in PET bottles (Fig. 6). Following the decreasing order of contamination by brands, MPCF was G > F > B > J > I > A > H > E > D > C.

According to the MPCF classification, 20% of all samples had moderate contamination and the remaining 80% had high contamination. When evaluated based on the packaging material, sixty percent of the Tetra Pak and all of the pet ones had high microplastic contamination. Since packaging components used in bottles and caps as well as anthropogenic effects are mentioned as potential sources for microplastic contamination in published studies (Makhdoumi et al., 2021; Shruti et al., 2020; Schymanski et al., 2018; Sobhani et al., 2020), it supports the study's conclusions. A score which is > 1, shows pollution by MPs for all soft drink brands analyzed in the current study.

3.4. Estimation of microplastic intake by adults and children

Table 2 indicates the estimated daily intake (EDI) for the children and adults. Adults had a consumption of 0.002–0.006 MP/kg/bw/day, while children had a higher intake of about 0.006–0.018 MP/kg/bw/day of soft drinks (Table 2). Estimated annual intake (EAI) was also computed as 2.19–6.57 MP/kg/bw/year for adults and children, respectively. Since EDI has not been estimated in previous studies conducted on microplastic pollution in soft drinks, this study's findings were compared with those performed with natural and mineral water.

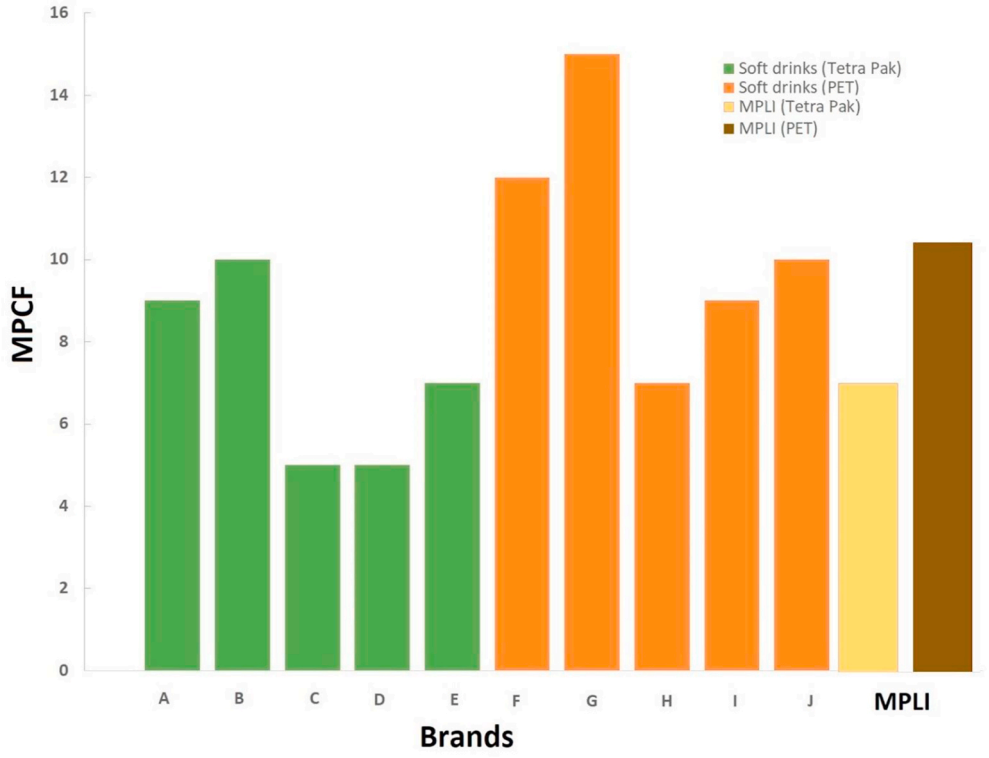


Fig. 6. Microplastic contamination factors and pollution load index in the Turkish soft drink.

Table 2
Comparative Estimated Daily Intake chart for children and adults at various levels of soft drink consumption in Türkiye.

Group	Microplastics particles in soft drinks (particle/L)	IR (L/day)	BW (kg)	particle/kg/day
Adults	5	3×10^{-2}	70	2×10^{-3}
	15	3×10^{-2}	70	6×10^{-3}
Child	5	2×10^{-2}	16	6×10^{-3}
	15	2×10^{-2}	16	18×10^{-3}

Our investigation's findings concurred with those of recent research (Makhdoumi et al., 2021) on mineral waters of Iran (EDI 0.015–0.065 MP/kg/bw/day for adults and children, respectively). Additionally, according to Zhou et al. (2021), the daily and annual EDI calculations in natural waters were made as follows: adult (0.274–7.32 MP) and child (0.6–16 MP). EDI values in mineral waters in Türkiye have been reported as 0.04 MP and 0.009 per day for children and adults, respectively (Altunışık, 2023). In contrast to previous research, Zuccarello et al. (2019) found that MP exposure was greater in both adults (0.274–7.32 MP (kg/bw/day/year)) and children (6–16 MP/(kg/bw/day/year)). The fact that the calculated values are higher in studies conducted in European countries compared to Asian countries can be associated with the per capita consumption in these countries, as well as the greater quantity of microplastics found in the analyzed samples. In addition, the quality of the bottled material, population trends, and consumption patterns, the storage conditions of the packages, and the MP detecting procedure are all parameters that can affect EDI (Winkler et al., 2019; Akhbarizadeh et al., 2020).

4. Conclusion

This is a pioneering study that determines the distribution, polymer type, shape, size, and color of microplastics in Turkish soft drinks. Microplastic particles were found in all ten soft drink brands. The study's findings showed that each liter of consumed soft drinks exposes people to about nine microplastic particles, which is a moderate dose when compared to exposure levels in earlier research. Eighty percent of the soft drink samples indicated a high level of contamination with microplastics. The highest microplastic concentration was detected in brands packaged in Tetra Pak. The pollution load was 6.9 and 10.25 for Tetra Pak and PET, respectively. The chemical components of these microplastic polymers, which were detected by F-TIR stereoscopy, were PET, PA and PE, and fibers were the most prevalent shape. The mean size of MPs in 214.03, and the dominant length range of MP was 50–100 μm. The results of the current study showed the EDI ranged between 0.002–0.006 and 0.006–0.018 particle/kg/bw/day for adults and children, respectively.

Author contribution

AA: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Writing – original draft; Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.117720.

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