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Microplastics in bottled water and bottled soft drinks

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ABSTRACT

The aim of the study was to evaluate the contamination of the bottled water and bottled soft drinks available on the Polish market by microplastics. The research confirmed that microplastics were found in each sample analyzed, regardless of the type of material from which the packaging was made. More microplastic particles were found in bottled water than in soft drinks. Based on the shapes and Fourier-transform infrared spectroscopy analysis, microplastics present in the samples were mainly secondary contaminants.

Keywords: Microplastics; Bottled water; Bottled soft drinks; Polyethylene terephthalate (PET)

1. Introduction

The market for bottled water and soft drinks is getting bigger every year. Despite many years of campaigns encouraging the direct consumption of tap water, there is a belief in society that it is only suitable for drinking with prior boiling. Hence the constantly growing sales of packaged water. For many decades, the most available material was glass. However, with the spread of the plastics industry, plastic packaging appeared on sale. Most of them are bottles made of polyethylene terephthalate (PET). They are characterized by low weight, high elasticity, low susceptibility to mechanical damage, and general ease of use. PET is one of the safest plastics for storing soft drinks and has many characteristics that make it ideal for bottled water. PET is an unbreakable rigid plastic that will not crack even if it breaks. These attributes make it an excellent material choice for storing bottled water and other soft drinks [1].

Bottled water producers are constantly working on reducing the weight of the bottle, thus reducing the amount of material needed for its production. This allows the companies to reduce production costs. PET bottles are fully recyclable. Unfortunately, due to the lack of functioning legal regulations that could limit waste generation, many of these bottles are not recycled, and their amount in the natural environment is increasing daily.

Bottle caps are generally made of polyethylene (PE). It is also non-toxic, durable, and resistant to external factors. As in the case of PET, it is recyclable, mainly with selective collection [1].

However, as the literature [2–5] shows, bottled water and soft drinks packaged in plastic may contain significant amounts of microplastics. Microplastics are now a common anthropogenic pollutant. It is found in inland waters and oceans, tap water, sewage, soil, and often in food. Microplastic is a broad term that does not differentiate the shape, size, origin, or type of polymer it is made of. It is assumed that these are plastic particles with dimensions smaller than 5 mm. However, it most often occurs in much smaller particles, much lower than a millimeter. The adverse effects of microplastic particles on aquatic organisms have already been proven, and scientific research shows that they accumulate in the organisms of humans and animals [6].

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It is equally interesting to learn about the ways in which microplastic particles into the human body. Considering the constantly growing production of water and soft drinks sold in plastic packaging, it can be suspected that they are a source of microplastics. Worldwide scientific research confirms the presence of tiny plastic fragments in the vast majority of commercially available bottled waters. Such studies are presented in this paper. The focus was on quantifying microplastics in randomly selected waters and soft drinks on the Polish market.

The plastic for the bottles is delivered in the form of PET granules. After entering the technological line, it is heated to a temperature of 260°C–3,000°C. This causes the granulate to melt and form a homogeneous mass, which is then injected into the mold. This is how the bottle preform is made. The next stage is heating the preform to a temperature of approximately 800°C, which makes it flexible. Then, it goes to the final mold corresponding to the shape of the target bottle, where it is blown to its final shape using high pressure. The last step is cooling it, thanks to which the bottle will keep its shape. The bottle production process is fully automated. Larger companies produce bottles independently, while smaller ones use ready-made bottles or preforms imported from suppliers [7,8].

The production process of plastic bottle caps is based on injection technology. The granulate (polyethylene, PE) is supplied to the hopper of the injection molding machine. Directly from it, it is directed to the screw, where it is plasticized at high temperatures. It is then injected into the mold under high pressure. The process must be carried out with the highest quality standards and meet the requirements of regulations on packaging intended for food products [7,8].

Both PET and PE are fully recyclable plastics. However, during recycling, they must be separated from each other, which is already tricky for the producers of these packages themselves (e.g., safety rings against opening most often remain on the neck of the bottle, making it difficult and, in extreme cases impossible, to reuse this waste as a raw material) [8].

Before produced bottles are filled with liquid, they are washed and then rinsed several times to remove residues from the production process. These can be microscopic particles of un-melted granules or foreign bodies that have gotten into the bottle. The next step is disinfection, for example, with UV rays. An essential element is the speed with which the bottle will go to the next production stage, preventing secondary interior contamination.

Under current legislation, testing for microplastics in water and bottled beverages is not required. Therefore, it is not a routine operation in production plants. This means that consumers do not have any information about what amounts of microplastics (in the form of PET and PE particles) enter their bodies through the bottles. This situation is to change because, by the EU Directive 2020/2184, it is assumed that no later than January 12, 2024, the Commission will have to submit a report to the European Parliament and the Council on the potential threat to sources of water intended for human consumption posed by, among others, microplastics regarding potential health risks. Furthermore, by January 12, 2024, the methodology for measuring the content of microplastics in water intended for consumption will have to be adopted [9].

The available data on microplastics in mineral waters and soft drinks are most often based on research on the foreign market. There is no reliable research on the waters sold in Poland. Therefore, the aim of the study was to demonstrate the presence of microplastics in consumed bottled waters and bottled soft drinks in Poland, and thus its presence in the diet of modern man. The authors quantified the content of microplastic particles in selected waters and bottled beverages and proposed an explanation of their origin.

2. Materials and methods

2.1. Types of bottles examined during the experiment

Four types of bottled water and two soft drinks commonly available in Polish grocery stores were selected for the study. Each time, six bottles of each brand were used for the tests. All tested samples of water and beverages were in polyethylene terephthalate (PET) bottles with a capacity of 1.5 dm^3 (the most popular packaging capacity for bottled water and soft drinks in Poland).

2.2. Quantitative analysis of microplastics

Before sample preparation, all elements used in the process (laboratory glassware, elements of the vacuum pump system, Petri dishes) were thoroughly washed with distilled water. Due to the possible deposition of microplastic particles from the air on the membrane filters, the samples were filtered under a fume cupboard. The sample preparation team wore white cotton aprons and latex gloves.

The preparation of samples for analysis consisted of filtering the entire contents of the bottle (1.5 dm^3) using the "Aga Labor" vacuum pump through membrane filters with a pore diameter of 0.45 μm. Due to the possible deposition of microplastic particles from the air on the filters, the samples were filtered under a fume cupboard. During percolation, the upper part of the pump suction vessel was also protected with a planktonic mesh. After filtering was complete, the filter was carefully transferred to a petri dish, and microplastic particle counts were performed under a microscope. A "Delta Optical" microscope with a maximum magnification of 90 times was used. Thanks to a camera coupled with a microscope, observations were carried out on a computer screen using the ScopeImage 9.0 program. The activities consisted of counting microplastic particles, supported by the scale on membrane filters. During the tests, the wall thickness of each bottle was also measured using a micrometer.

2.3. Statistical analysis

Four samples of water and two soft drinks were used for the study. Four replicates of each sample of water and soft drink were analyzed. The data for each sample was expressed as a mean with a standard deviation (SD) and a relative standard deviation (RSD). The standard deviation was calculated by using STATISTICA software.

2.4. Qualitative analysis of microplastics

Qualitative analysis of microplastics was performed by using a FTIR 6200 Jasco spectrophotometer coupled with an ATR PRO One View, Jasco.

3. Results and discussion

The research was conducted to determine the microplastics in bottled water and soft drinks. Microplastic particles were quantified and grouped according to shape. Table 1 summarizes the ranges of microplastic amounts in individual samples. The average microplastics content in bottles and per m^3 of water or beverage was calculated, and SD and RSD values were given. All samples tested showed the presence of microplastics. The lowest concentration of microplastic particles was found in samples of soft drinks (1–3 particles per bottle, that is 1,000–1,500 per m^3 of liquid), while much higher concentrations were found in bottled water (5–25 particles per bottle, that is 4,167–14,556 per m^3). The results of measuring the thickness of the walls of the bottles from which the liquid samples came were also presented.

Fig. 1 shows the percentage division of microplastic particles by shape. Most plastic particles are microfibers, which account for 80% to 90% of the microplastics in bottled waters and 60% to 70% in soft drinks. Between 8% and 12% of bottled waters were fragments; in soft drinks, it was 30% to 40%. Microbeads were also found in bottled waters, accounting for 2% to 10%, while in the case of two types of bottled waters and soft drinks, they were not found.

The research results indicate that bottled water and soft drinks commercially available on the Polish market contain microplastic particles. Although the research was conducted on a random sample of both bottled waters and soft drinks, it can be seen that the content of microplastics was higher in bottled waters than in soft drinks (water: 5–25 MP per bottle, soft drink: 1–3 MP per bottle). The results from mineral waters in PET bottles are similar to research on Iranian and Saudi Arabian bottled waters [10,11]. The vast majority of microplastic particles were in the form of fibers, often spirally twisted. According to the authors, the microplastics observed in bottled waters and beverages are secondary contaminants. It comes from unscrewing and capping bottles, as confirmed by research [12,13]. The studies of Weisser et al. [14] found that unfilled bottles are almost free of microplastics, with most of the microplastics coming from unscrewing the caps and sealing the caps, which is also in line with the results of this study. PET (bottle) and PE (cap) rubbing against each other undergo a process that could be called "cutting". The colors of the microplastic fibers are very similar to the colors of the bottles (transparent with a blue or green tint) (Fig. 2) and opaque blue, green, and red (cap colors). In two cases, transparent red fibers were observed (Fig. 3) in bottles where the cap and the packaging were not of this color. According to the authors, this may indicate water contamination at the packaging production or bottling stage. Confirming this fact is also the presence of microgranules in water samples (Figs. 4 and 5), in which case there is a low probability that they come from unscrewing and capping bottles.

Analysis of the microplastics quantified during the study showed that most of them were PET particles. An

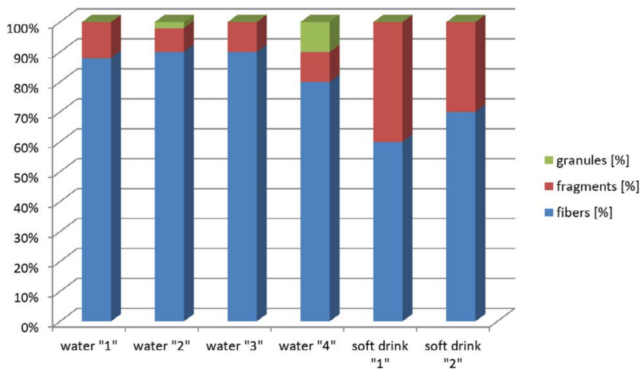

Fig. 1. Percentage of microplastic particles forms.

Fig. 2. Colored and transparent fibers—bottled water.

Table 1
Microplastic in samples taken from bottled water and bottled soft drinks

Sample	Water "1"	Water "2"	Water "3"	Water "4"	Soft drink "1"	Soft drink "2"
Range in bottle	18–25	11–13	8–13	5–10	1–3	1–2
Average per bottle	21.83	13.50	10.67	6.25	2.25	1.50
SD	2.64	1.87	1.86	2.58	0.75	0.55
RSD (%)	12.1	13.9	17.4	41.3	34.6	35.3
Average MP in 1 m^3 (amount of particles/m^3)	14,556	9,000	7,111	4,167	1,500	1,000
Average thickness of the bottle's wall (mm)	0.21	0.21	0.17	0.20	0.16	0.26

example of the FTIR spectrum for PET microplastics is presented in Fig. 6. As can be seen in Fig. 6, the spectrum does not match perfectly to the PET spectrum standard given by Peltzer and Simoneau [15]. Bach et al. [16] showed that this phenomenon is typical for recycled PET materials. Recycling of PET products can be done via [17]:

- mechanical processes—they consist of separation, washing, and grinding of the bottles,
- chemical processes—they consist of separating the basic components or monomers, for example, by methanolysis, glycolysis, and hydrolysis.

As a result of recycling processes, some unknown compounds are present in the PET, and as a result, changes in the FTIR spectrum compared with the standard are visible [16].

However, it is not easy to compare the data obtained in the presented studies with the data of other authors because the definition of individual plastic molecules is not always clear. It seems that many authors refer to “fibers” only as microplastics from clothing, while referring to plastic particles with an elongated shape (looking like threads) as “fibers”.

Since microplastics are now a common environmental pollutant, they are also found in products consumed. It is

Fig. 3. Colored fiber—bottled water.

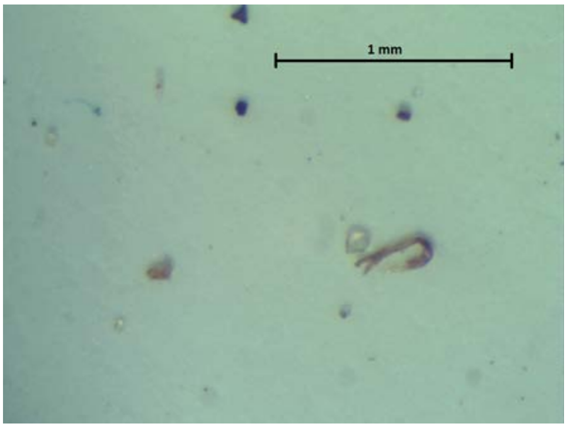

Fig. 4. Fiber and granule—soft drink.

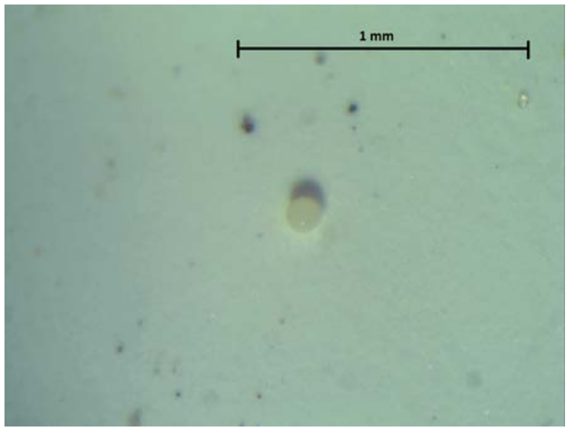

Fig. 5. Granule—bottled water.

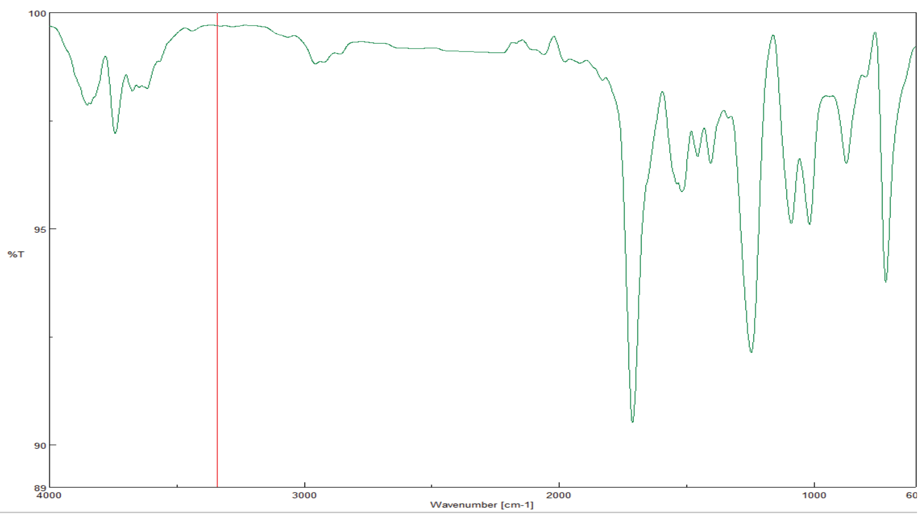

Fig. 6. Exemplary FTIR spectrum for PET commercial samples found in the bottled water.

absorbed daily by breathing air and food. It seems that a few or a dozen particles of microplastics consumed with the water or beverage you drink are not much. However, taking into account that these amounts are much higher than the content of microplastics in, for example, tap water [13], the point of view changes entirely. In the current constant increase in the consumption of beverages sold in plastic packaging, is it possible to reduce the amount of microplastic introduced into the human body? This seems unlikely. Resigning from plastics in everyday life is currently rather impossible, and it will bring more problems than benefits. It is important to consciously use all kinds of products, including water and drinks, packaged and stored in plastic packaging. Often, a change in habits and, above all, changes in packaging production technology can significantly contribute to reducing the exposure of human organisms to the absorption of microplastics. Comparing the results of the presented research with the results obtained by other authors, it can be seen that the amount of microplastics in water and bottled beverages varies within vast limits.

There is much information about microplastics in bottled water nowadays. The authors compared this study's results with foreign scientists' studies. They found that despite significant discrepancies in the amount of microplastics, in European countries (Germany, Poland), the amounts of microplastics are lower than in the countries of Asia and America (Table 2). However, in the case of soft drinks, there needs to be more scientific information. The available data show that the level of microplastic contamination of soft drinks in other countries is similar to that of bottled water (approximately 10,000 particles/m^3). However, this does not apply to soft drinks from Poland because they are ten times lower when comparing the amounts of microplastics with the results from other countries (Table 3).

The authors of this article noticed that one of the factors increasing the number of microplastics was the "immeasurable" property of the bottles during the research—some of them were "soft", that is after partial emptying, they "bent" under the weight of the liquids contained in them. Others, however, did not undergo such deformations. Significantly more microplastics were found in "soft" bottles. There was no relationship between the thickness of the bottle walls (ranging from 0.16 to 0.26 mm) and the microplastics content (Table 1). It is also worth noting that the content of microplastics does not depend on the "brand" of a given product—even "unbranded" products, available in nationwide retail chains (soft drink 1), may contain much smaller amounts of microplastics compared with products of recognized brands (water "1" and water "3"). It is worth noting that manufacturers are constantly striving to reduce the amount of plastic in which their products are packaged. These observations are consistent with studies by Zuccarello et al. [19,25], who found that the number of MPs particles in bottled mineral waters was strongly correlated with the density of the bottle plastic. In Poland, advertising campaigns inform people that this is related to caring for the natural environment. However, it is easy to notice that reducing the weight of plastics has a financial dimension primarily—it is possible to generate more profits on a global scale. In the case of responsible management of secondary raw materials, such as plastic bottles, such actions make much sense. However, in the case of the method of waste disposal still preferred by the majority of society (throwing away anywhere), it contributes to the generation of much more significant amounts of microplastics—packaging that generates more microplastics during use will also be subject to mechanical degradation in the environment much easier (wiping erosion, fragmentation).

Table 2
Content of microplastic particles in bottled water

Country	Number of MP particles (particles/m^3)	References
China	2,000–23,000	Zhou et al. [18]
Germany	2,649 ± 2,857	Oßmann et al. [2]
Iran	8,500 ± 10,200	Makhdoumi et al. [19]
Malaysia	11,700 ± 4,600	Praveena et al. [12]
Thailand	140,000 ± 19,000	Kankanige and Babel [20]
USA	20,348 ± 3,404	Abdulmalik [21]
Poland	4,167–14,556	Current study

Table 3
Content of microplastic particles in soft drinks

Country	Number of MP particles (particles/m^3)	References
Italy	9,500	Salvagente [22]
Turkey	10,400	Altunışık [23]
Italy	9,940 ± 330	Crosta et al. [24]
Poland	1,000–1,500	Current study

4. Conclusions

The research results on the Polish bottled water market largely coincide with the research from other countries. Microplastics were found in each of the bottles that were tested.

Regardless of the type of material from which the packaging was made, the presence of microplastic particles was found during the tests.

More microplastic particles were found in bottled water than in soft drinks.

The shape and color of microplastic particles suggest that they may be a secondary contaminant of water and beverages resulting from packaging (unscrewing or capping bottles).

Currently, is not possible to determine how the individual stages of the technological process of production, bottling of water and beverages, and how bottles are used may affect the penetration of microplastic particles into water.

It is essential to identify the critical stage where water contamination is most likely to occur so that it will be possible to assess the effectiveness of the applied solution after making changes at this stage.

An important factor influencing the possibility of microplastics getting into the water is the packaging. The essence of the problem is its type, the impact of UV radiation, and other external factors on the structure of the bottle wall and the material from which the bottle was made.

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