ORIGINAL PAPER

INSIGHTS INTO THE PRESENCE, CHARACTERISTICS, AND POTENTIAL RELATED RISKS OF MICROPLASTICS FROM ORAL CARE PRODUCTS

RALUCA MARIA BUCUR (POPA)[1], CRISTIANA RADULESCU[1,2,3*], RALUCA MARIA STIRBESCU[4*], ANDREEA LAURA BANICA[1,4], IOAN ALIN BUCURICA[4], IOANA DANIELA DULAMA[4]

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Abstract. *Microplastics pose a significant risk to human health and the environment. This research examines microplastics in oral care products, particularly mouthwash, using morphological and chemical characterisation. A robust isolation protocol ensured the sample matrix was representative. Evaluation of digestion methods found that weak acids were ineffective and that strong oxidants were damaging to polymers. While alkaline treatment is feasible, the peroxide-based method proved optimal. Comprehensive characterisation is required to combine optical microscopy with micro-FTIR screening to ensure reliable data. A health risk assessment found that polypropylene and amorphous acrylate polymers in mouthwash pose a moderate to high risk for both adults and children.*

Keywords: *microplastics; mouthwash; micro-FTIR; health risk.*

1. INTRODUCTION

Plastic waste from our daily lives eventually enters the environment, where it can persist for centuries, gradually breaking down into smaller pieces. These tiny fragments, usually less than 5 mm, are called microplastics (MPs). They are sometimes added to cosmetics for specific purposes, such as exfoliating beads in facial or body scrubs (i.e., microbeads) or as decorative glitters in makeup products [1-3]. On September 27, 2023, the European Chemicals Agency (ECHA) announced a restriction on the use of synthetic polymer microparticles, commonly known as microplastics. This regulation, officially labelled as Commission Regulation (EU) 2023/2055, requires suppliers to include the statement "*This product contains microplastics*" on cosmetic labels if these substances are used in the product [4]. In addition to microplastics deliberately added to rinse-off or makeup products, many cosmetic products for skin care or treatment contain unintentionally present particles [5]. These microplastics, with structures unfamiliar to cosmetic manufacturers, could pose a risk to human health. Usually, the risk to humans comes from dermal contact, but for oral care products like toothpaste and mouthwash, the main risk is ingestion [6].

[1] National University of Science and Technology Politehnica of Bucharest, Doctoral School Chemical Engineering and Biotechnology, 060042 Bucharest, Romania. E-mail: ralucamaria.bucur@gmail.com.
[2] Valahia University of Targoviste, Faculty of Sciences and Arts, 130004 Targoviste, Romania.
[3] Academy of Romanian Scientists, 050044 Bucharest, Romania.
[4] Valahia University of Targoviste, Institute of Multidisciplinary Research for Science and Technology, 130004 Targoviste, Romania. E-mail: banica.andreea@icstm.ro; bucurica_alin@icstm.ro; dulama.ioana@icstm.ro.
[*] *Corresponding authors:* cristiana.radulescu@valahia.ro; stirbescu.raluca@icstm.ro.

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It is well known that oral care products, including mouthwash, are designed to promote complete oral hygiene. Sometimes, the ingredients in these products are not well understood by consumers. Each one serves a distinct purpose, such as freshening breath, protecting against cavities, preventing plaque build-up, or whitening teeth. The ingredients in oral care products undergo rigorous testing to assess their safety profile for oral use. Testing includes assessing their potential to cause acute toxicity, irritation, and sensitisation. Regulatory authorities, such as the FDA, set guidelines and specify acceptable limits for ingredients. These measures ensure their safe use in oral care products [7]. Depending on their intended use, the main types of mouthwash are [8]: *(i)* cosmetic, designed to freshen breath and gradually whiten teeth. This type of product contains ingredients that address cosmetic issues such as bad breath and teeth whitening, as well as medical issues such as gum bleeding, tartar build-up, and cavities [9]; *(ii)* therapeutic, which contains active ingredients (e.g., chlorhexidine, cetylpyridinium chloride, fluoride, hydrogen peroxide, and essential oils) that kill bacteria and reduce dental plaque [10-12], thereby protecting against gingivitis [13], the most common gum disease. On the other hand, mouthwashes containing antibacterial and antioxidant components have been shown to prevent periodontal disease [14]. These types of mouthwash are generally certified by relevant authorities, which confirm that the product delivers the promised results and recommend it to dentists.

Although oral health is considered an essential part of daily hygiene, concerns have been raised about microplastics released from plastic-based dental materials and oral care product formulations [15]. As with other oral hygiene products (e.g., toothpaste, mouth spray, and dental floss), using mouthwash can release microplastics into the mouth, thus increasing the risk of ingestion. Research has revealed the presence of microplastics in various biological fluids of the human body, such as sputum, urine, and blood [16,17]. On the other hand, ingestion of microplastics poses direct and indirect health risks, exacerbating chronic diseases such as diabetes, endocrine illness, cardiovascular and lung diseases, as well as reproductive disorders [18]. In addition, ingested MPs can impose physical or chemical stress on the digestive and circulatory systems. Irritation or damage to the digestive tract is also a possible outcome of microplastic exposure, with consequences for gastric function and overall digestive health [19,20].

Previous studies by Popa et al. have shown that microplastics are present in a wide range of cosmetic products, including shampoo, shower gel, hand soap, micellar water, micellar oil, and body spray, as well as in skincare and dermatocosmetic formulas [21-25]. Taking the above findings into account, this study investigated the presence of microplastics in mouthwash and the potential risk they pose to humans when released into the environment. The microplastics were quantified and characterised by composition and morphological properties (i.e., size, shape, colour, and type). Based on a voluntary survey, the exposure and potential health risks associated with microplastics released by mouthwash were also assessed.

2. MATERIALS AND METHODS

2.1. SELECTION OF MOUTHWASH PRODUCTS

A total of five well-known mouthwash brands (Table 1), collected randomly from different stores in Romania, were included in the analysis. These selected brands have extensive distribution across Romania, and their selection was based on survey data, taking into account the human category (i.e., adults and children, Table 1). The study examined 30

samples, with triplicates from each of the five brands, to assess the presence and potential risk of microplastics in these common mouthwash brands.

Table 1. Type, ingredients, and recipient category of branded mouthwash.

Sample	Chemical composition according to the supplier (highlighted on label)	Category
OCP_1	Water, glycerin, propylene glycol, sorbitol, tetrapotassium pyrophosphate, polysorbate 20, tetrasodium pyrophosphate, zinc citrate, pvm/ma copolymer, flavor, benzyl alcohol, sodium fluoride, sodium saccharine, CI 42051[(1)]	Adult
OCP_2	Water, eucalyptol 0.092%, menthol 0.042%, methyl salicylate 0.060%, thymol 0.064%, alcohol, flavor, benzoic acid, green 3, methyl salicylate, yellow 10[(2)], poloxamer 407[(3)], sodium benzoate, sodium saccharin, sorbitol.	Adult
OCP_3	Water, glycerin, alcohol denat[(4)], sorbitol, chlorhexidine digluconate solution 20%, poloxamer 407[(3)], flavor, CI 42051[(1)].	Adult
OCP_4	Water, glycerin, xylitol, aloe barbadensis leaf juice, citric acid, potassium sorbate, sodium benzoate, polysorbate 20, aroma, *Mentha arvensis* oil, epigallocatechin gallate, CI 16255[(5)].	Children
OCP_5	Water, glycerin, hydrogenated starch hydrolysate, xylitol, potassium sorbate, cocamidopropyl betaine, sodium benzoate, aroma, *Mentha arvensis* herb oil, sodium chloride, sodium saccharin, SI 42051, sodium sulfate.	Children
OCP_6	Water, sorbitol, aroma, sucralose, phosphoric acid, cetylpyridinium chloride, sodium fluoride, menthol, disodium phosphate, benzyl alcohol, CI 16035[(6)], CI 42053 [(7)], sodium fluoride (0.022% w/v 100 ppm F).	Children

[(1)] CI 42051, according to IUPAC, is named calcium;4-[[4-(diethylamino)phenyl]-(4-diethylazaniumylidenecyclohexa-2,5-dien-1-ylidene)methyl]-6-hydroxybenzene-1,3-disulfonate, (dark bluish dye);
[(2)] Yelow 10 acording to FDA is 2-(2-quinolyl)-1,3-indan dione disulfonic acid disodium salt;
[(3)] Poloxamer 407, according to IUPAC, is called poly(ethylene glycol)-block-poly(propylene glycol)-block-poly(ethylene glycol), as a non-ionic detergent;
[(4)] Alcohol denat means denatured ethanol – a mixture of ethanol and ethyl acetate.
[(5)] CI 16255, according to IUPAC, is named trisodium 1-(1-Naphthylazo)-2-hydroxynaphthalene-4',6,8-trisulphonate (red dye known in cosmetics as cochineal Red A or Ponceau 4R/Acid Red 18);
[(6)] CI 16035, according to IUPAC, is called disodium 6-hydroxy-5-[2-methoxy-4-sulfonato-m-tolyl)azo]naphthalene-2-sulfonate (Red dye 17);
[(7)] CI 42053, IUPAC name is dihydrogen(ethyl)[4-[4-[ethyl(3-sulphonatobenzyl)amino](4-hydroxy-2 sulphonatobenz hydrylidene]cyclohexa-2,5-dien-1-ylidene](3-sulphonatobenzyl)ammonium (Fast Green FCF).

2.2. MICROPLASTICS ISOLATION METHOD

The microplastic isolation method comprised three simple, rapid steps. First, 5 g of the sample were pretreated with ultrapure reagents, including 10 mL of 30% hydrogen peroxide (H_2O_2, Merck, Darmstadt, Germany). This was required for mineralising the organic matrix of oral care products. After adding 50 mL of ultrapure water, the mixture was homogenised by stirring at 150 rpm for 10 minutes. Second, digestion was performed by ultrasound at 30°C for 20 minutes. Third, samples were vacuum-filtered onto filter paper with a 12–15 μm pore size. The method was also classified as ecological, fast, and low-cost. All reactants were of high purity. To avoid contamination, the materials were carefully cleaned and prepared in a Class 1000 cleanroom (see Section 2.4). A Millipore Milli-Q IX 7015 Water Purification System (Merck, Darmstadt, Germany) ensured high-quality water for the isolation method.

2.3. ANALYTICAL TECHNIQUES

2.3.1. Optical Microscopy

Microparticles from mouthwash samples were identified using optical microscopy (OM). Identification, quantification, and characterisation were performed at 40x

magnification (200 µm) on the filter's surface. The Primo Star microscope (Carl Zeiss Microscopy GmbH, Jena, Germany) examined microparticles in transmitted light. Images were acquired using an Axiocam 105 digital video camera (Carl Zeiss Microscopy GmbH, Jena, Germany) and Zen 2012 software (version 1.1.2.0).

2.3.2. Micro-Fourier Transform Infrared Spectroscopy

The most common vibrational method for evaluating molecular motion and identifying species is Fourier-transform infrared spectroscopy (FTIR). This method uses the 400-8000 cm^{-1} range to measure inelastic scattering from a monochromatic source. Micro-FTIR is a key non-destructive, non-invasive technique. It offers FTIR imaging, such as particle analysis and multi-spot testing, and analyzes minute chemical differences, including area or line mapping. This yields specific information about chemical bonding and molecular structure [26,27]. The vibrational method applied to isolated microparticles on the filter surface utilized a Vertex 80v spectrometer with a diamond ATR and Hyperion 2000 microscope (Bruker Optics GmbH & Co. KG, Ettlingen, Germany). The Hyperion microscope has ±1 µm precision, a 600-7500 cm^{-1} spectral range, and 0.2 cm^{-1} spectral resolution. For each sample, 32 scans were performed. The resulting polymer spectra were compared to OPUS v.7.5 library reference spectra (Bruker Optics GmbH & Co. KG, Ettlingen, Germany). A spectral match of 75% or higher confirmed the polymer type, as described by Karthik et al. [28] and Veerasingam et al. [29].

2.4. QUALITY ASSURANCE AND QUALITY CONTROL

Quality control (QC) and quality assurance (QA) measures were meticulously applied throughout the analytical investigations. These ensured the accuracy and dependability of the research. Strict safety measures were used throughout the study to prevent sample contamination. All steps followed ISO 14644-1:2015 [30], as suggested by several authors [31-33]. The examined mouthwashes were opened directly in the Class 1000 clean-room facility. No tubes, Teflon containers, or other tools were used for sample handling outside the laboratory. Distilled water and reagents were filtered before use on VWR Grade 413 filter paper (porosity 12–15 µm) (VWR International, Radnor, PA, USA). All laboratory operations took place on surfaces cleaned with 70% ethanol. This step followed the approach described by Zhang et al. [34].

For user safety precautions: *(i)* cotton laboratory coats and non-synthetic clothing were worn to prevent textile fibre shedding; *(ii)* disposable sterile masks, gloves, and caps were used. In addition, glassware was cleaned with distilled water and 2% nitric acid. It was sterilised in a Venticell forced-convection oven (BMT Medical Technology Ltd., Brno, Czech Republic) at 100°C for 48 hours. The glassware was then covered with aluminium foil. The utmost care was taken to ensure the cleanliness and purity of all laboratory equipment and glassware. These items were meticulously cleaned three times with filtered ethanol and then twice with Milli-Q water, before both sampling and processing.

The working area was thoroughly cleaned before the optical microscope, and a micro-FTIR spectrometer was used. This reduced the risk of cross-contamination. When not in use, all study equipment (a vacuum pump, oven, water bath, ultrasonic bath, filtration system, and a five-position heating stirrer) was covered with aluminium foil to prevent airborne contamination by polymetallic microparticles. The filters were safely transferred to the optical microscopy and spectroscopy laboratories for examination. This strategy helped

guarantee sample security throughout preparation, testing, and analysis. It is one of the most important steps in reducing sample contamination. After filtration, optical microscopy was used to examine the filters from the ultrapure water and the 30% H_2O_2 reagent. No contamination was observed on their surfaces. One filter was also analysed under a microscope to confirm the presence of microparticles on its surface.

2.5. DATA ANALYSIS

Daily use of oral care products not only creates a beautiful smile and improves overall health but also helps prevent oral diseases. However, recent studies have highlighted concerns about microplastics in cosmetics, as detailed in the author's research papers [21-25, 35-37]. Building upon these findings, the toxicity of microplastics and the risks associated with their ingestion following use of oral care products were assessed using specific risk calculations. To quantify these risks, values for the Polymer Risk Index (H), Daily Plastic Intake (DPI), Estimated Annual Intake (EAI), and Chronic Daily Intake through Ingestion (CD_{Ing}) were calculated for adults and children, based on research by Banica et al. [38].

Polymer risk index (H) was calculated based on Equation (1):

$$\mathrm{H} = \sum P_i \cdot S_i \tag{1}$$

where P_i is the percentage of polymers identified in the analyzed fragments and fibers, and S_i represents the polymer risk factor. The polymer risk factor was established by Lithner et al. [39]. S_i for poly(methyl methacrylate) and polypropylene are 1021.0 and 1.0, respectively.

In both science and medicine, daily plastic intake is a serious concern. Equation (2) adopted by Banica et al. [38] from Binelli et al. [40] led to the stability of daily plastic consumption.

$$\mathrm{DPI} = I_r \cdot C_i \tag{2}$$

where I_r is the amount of mouthwash used in one rinse (20 mL·application^{-1}), and C_i, expressed as n·kg^{-1}, is the content of MPs identified in the analyzed samples.

The estimated annual consumption (EAI) of microplastics from oral care products was calculated based on Equation (3) [41], where the number of microplastics (C_i) identified in the analyzed samples and the annual consumption rate (*AIR*) of mouthwash (365·20 mL product) were taken into account.

$$\mathrm{EAI} = C_i \cdot AIR \tag{3}$$

Chronic daily intake through ingestion (CDI_{ng}) was calculated for adults and children, based on Equation (4) presented by Leslie et al. [16] and Aralu et al. [42].

$$CDI_{ng} = \frac{C_i \cdot I_r \cdot E_d \cdot E_f}{B_w \cdot A_t} \cdot CF \tag{4}$$

where E_d is the duration of exposure to oral care products, expressed in years (14 years for children and 70 years for adults); E_f represents the exposure to microplastics from mouthwash

use (expressed as day·year^{-1}); B_w is the body weight, expressed in kg (48 kg for children and 70 kg for adults); A_t represents the average exposure time, i.e., 365 days; and *CF* represents the conversion factor ($1 \cdot 10^{-6}$).

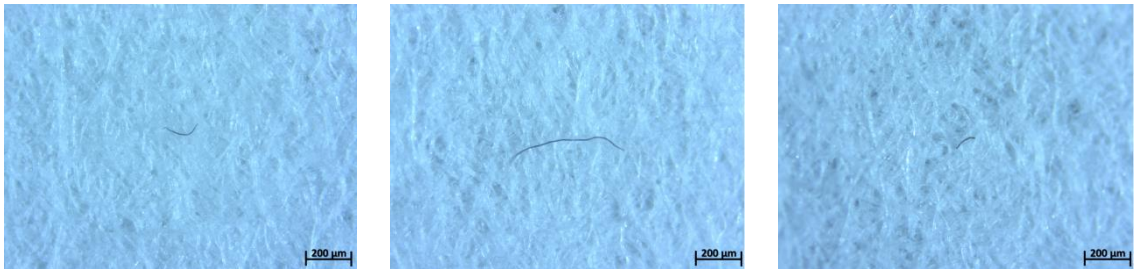
3. RESULTS AND DISCUSSION

This research continues the three-year investigation of a series of cosmetics (i.e., shampoo, shower gel, liquid soap, skincare and treatment creams, micellar water, body spray, micellar oil, body oil, oral care health, including mouthwash and toothpaste) used daily by people of all ages in Romania [21-25]. The questionnaire [25] used in this study showed that the Romanian population uses mouthwash for dual purposes: care or treatment of oral illness. Results indicate that both world-renowned and nationally recognised mouthwashes are commonly included in daily oral health routines. These practices have been associated with measurable reductions in microplastic contamination in the environment, as documented in the findings. The study highlights the potential environmental impact of daily cosmetic and mouthwash use, emphasising the importance of assessing product choices and public awareness to reduce microplastic pollution.

3.1. QUANTIFICATION AND MORPHOLOGICAL CHARACTERIZATION OF MICROPLASTICS

Optical microscopy was the first analytical technique used to quantify microparticles in mouthwash samples. Here, 'microparticles' refers to all detected particles. Optical microscopy provided initial insights into their shape, size, and colour. These features are vital for source apportionment and risk evaluation. Previous studies [21-24, 33, 43, 44] on microparticle morphology, including fibres, fragments, and films, indicated the presence of microplastics in the samples (Fig. 1). Building on these findings, the subsequent analysis specifically addressed challenges in detecting and characterising smaller particles.

Detection and characterisation of smaller-sized particles present additional challenges. Studies show that standalone optical microscopy has a minimum size threshold of 200.0 μm to 1.0 mm, making visualisation and interpretation of such particles difficult. As particle size decreases, assessing colour and morphology becomes more difficult. This also complicates the identification of whether a particle is of anthropogenic origin, as manufactured features such as pellets, spheres, or vivid colours are harder to assess. Microparticles that are black, brown, white, or translucent are more easily misidentified than those with bright colours such as red, blue, turquoise, or grey. According to data shown in Table 2, black, blue, red, turquoise, and grey microparticles were identified in the six samples.



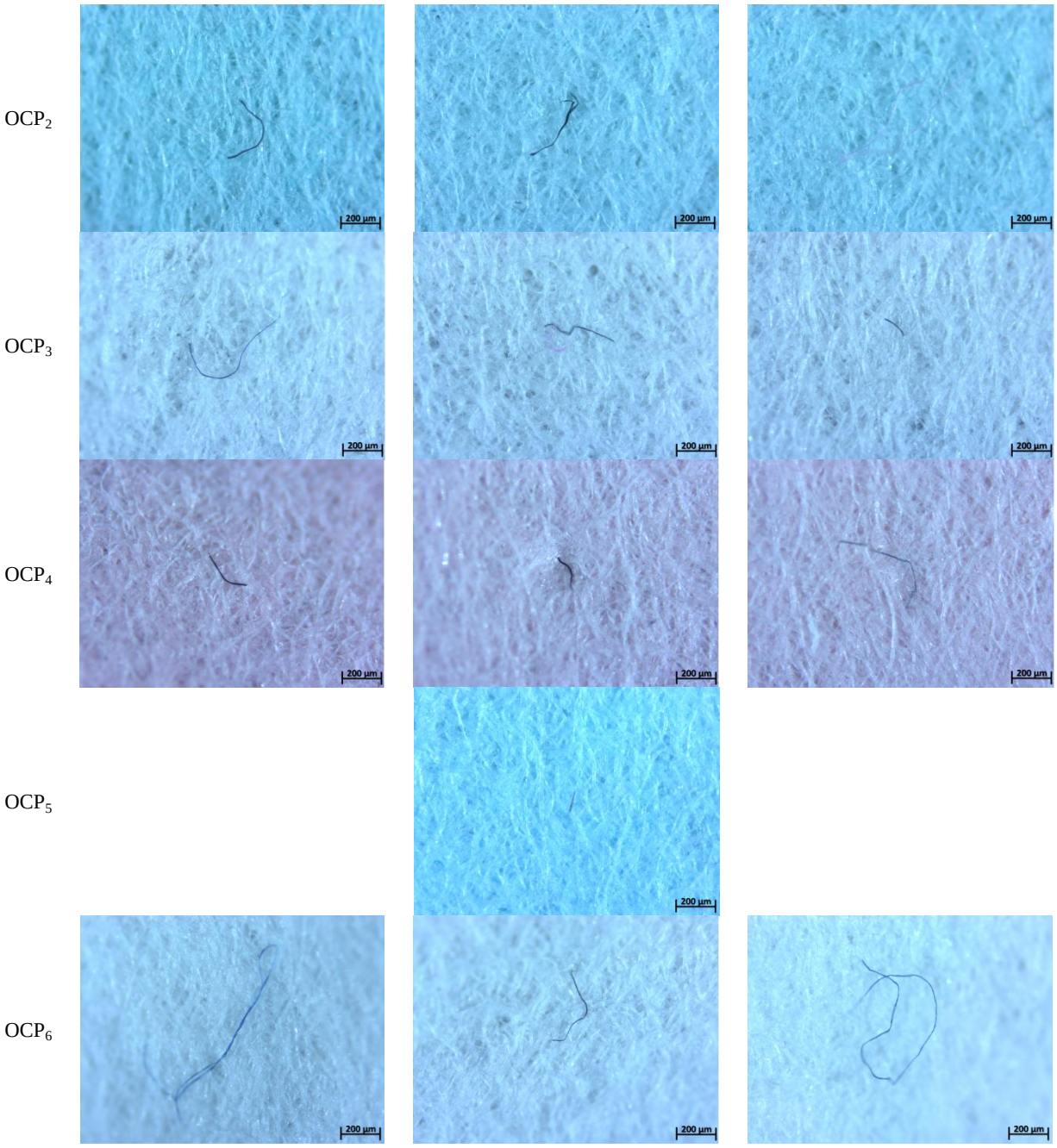


Figure 1. Optical microscopy images of representative MPs identified in oral care products.

Turquoise and grey microparticles were found in one sample each (OCP_2 – grey microparticles and OCP_4 – turquoise microparticles). Based on the number of microparticles, the mouthwash samples analysed are classified as follows: $OCP_5 < OCP_1$ and $OCP_2 < OCP_4 < OCP_3 < OCP_6$. Microparticles were easily identified by shape, as they exhibit characteristic fibre types (Table 2).

Table 2. Morphological features of microparticles assessed by optical microscopy and micro-FTIR spectroscopy.

Characteristic	Typology	Value [n·L^{-1}]	Analytical techniques
Colour	Black	333.33±168.03	Optical microscopy (natural and synthetic microparticles)
	Blue	477.78±376.60	
	Red	100.00±102.90	
	Turquoise	77.78±100.33	
	Grey	88.89±140.96	

Characteristic	Typology	Value [n·L^{-1}]	Analytical techniques
Shape	Fibers	1100.00±532.92	
Size [µm]	< 50 µm	133.33±115.47	Micro-FTIR/ OPUS v.7.5 (microplastics)
	50-100 µm	66.67±115.47	
	100-500 µm	1533.33±416.33	
	500-1000 µm	2133.33±305.51	
	> 1000 µm	333.33±230.94	

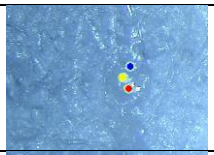
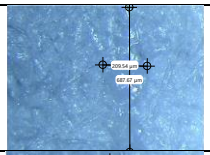
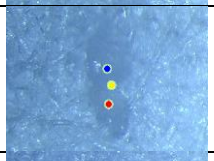
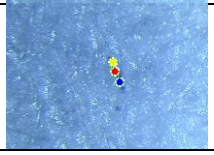
Microparticles were detected in all mouthwash samples, with concentrations ranging from 200 to 1800 microparticles·L^{-1} and an average abundance of 1100 microparticles·L^{-1}.

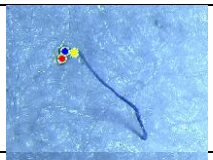
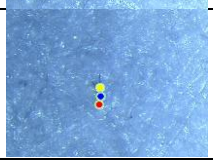
3.2. MICROPLASTICS IDENTIFICATION AND CHEMICAL CHARACTERIZATION

Increased subjectivity in data interpretation leads to greater human error and lower accuracy, requiring additional analytical steps to identify microparticles by polymer type. In this regard, analytical techniques such as micro-Fourier transform infrared spectroscopy (micro-FTIR), Raman microspectroscopy (micro-Raman), and pyrolysis-gas chromatography-mass spectrometry (Py-GCMS) are widely used. Sometimes, combining optical microscopy with spectroscopic imaging techniques offers the best alternative for a comprehensive morphological and chemical characterization of microparticles, including microplastics.

Micro-FTIR is a valuable method for identifying and characterising microplastics based on their morphological and chemical structures. The morphotypes identified in the samples were fibre (100%) shapes, including irregular and short *vs.* filamentous and continuous, unbroken (Tables 2 and 3). Additionally, all detected microplastics were smaller than 1.0 mm, with those smaller than 50 µm accounting for 100% of the total across samples (Table 2). In this regard, although optical microscopy identified numerous and various microparticles, only micro-FTIR can distinguish naturally occurring from synthetic microparticles. Regarding the chemical composition of the microplastics found in the samples, one sample matched 100% polymer, and another showed a polymer: natural mixture (Table 3). Polypropylene was the most prevalent in both samples, OCP_1 and OCP_3.

Table 3. Data related to chemical and morphological characteristics of microplastics from samples.

Sample code	Micro-FTIR image	Composition of MPs [%]			Micro-FTIR image
		PP[1]	PMMA[2]	Cotton	
$OCP_{1.1}$		100	na	na	
$OCP_{1.2}$		100	na	na	
$OCP_{3.1}$		100	na	na	

Sample code	Micro-FTIR image	Composition of MPs [%]			Micro-FTIR image
		PP[1]	PMMA[2]	Cotton	
$OCP_{3.2}$		na	50	50	
$OCP_{3.3}$		100	na	na	

[1]*PP – Polypropylene;* [2]*PMMA - Poly(methyl methacrylate).*

Selected spectra for identified MPs in the samples are shown in Figs 2 and 3. Notably, a mixture of natural and synthetic fibres was identified in OCP_3 samples (Table 3). In the three analysed samples designed for children, the microplastics were avoided.

Micro-FTIR analysis identified the polymer type in microplastic samples. In this regard, samples OCP_1 and OCP_3 had fibres matching polypropylene structures, as shown by the Opus v.7.5 Library Reference Spectra (Bruker, Germany) in Fig. 2. The literature recommends a minimum hit-quality index (HQI) of 75% for a polymer match, which serves as a threshold for validating a match between the reference and sample spectra [28, 29]. Peaks at 2951–2839 cm^{-1} (C–H stretch), 1457 cm^{-1} (CH_2 bend), and 1376 cm^{-1} (CH_3 bend) confirm that the polymer composition of the fibres is polypropylene. The peak at 1167 cm^{-1} is linked to CH bending, CH_3 rocking, and C–C stretching. On the other hand, the peak at 997 cm^{-1} is assigned to CH_3 rock, CH_3 bend, and CH bend. Transmittance peaks at 973 cm^{-1} (CH_3 rock, C–C stretch), 841 cm^{-1} (CH_2 rock, C–CH_3 stretch), and 808 cm^{-1} (CH_2 rock, C–C stretch, C–CH stretch) further support the polypropylene structure. It should be noted that only polypropylene fibres, as microplastics, were detected in two randomly selected mouthwash samples, regardless of brand or supplier. These findings align with those of Jung et al. (2018) [45] for polypropylene identification, taking into consideration that the HQI values indicate that the primary characteristic peak shape and fingerprint peaks of polypropylene remained unaltered [28,29].

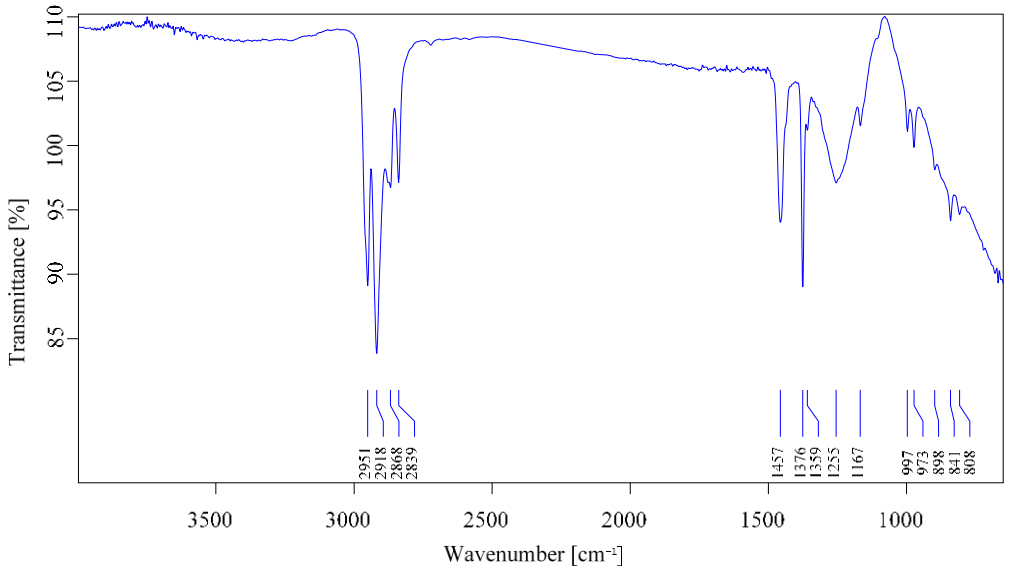


Figure 2. FTIR spectra of samples OCP_1 and OCP_3 match the Opus v.7.5 Library polypropylene spectrum.

Results indicate polypropylene in two mouthwash samples, except for one fibre in OCP_3, which was a mixture of poly(methyl methacrylate) and cotton. According to Fig. 3, the spectrum of the PMMA: cotton 50:50 mixture in sample OCP3 matches that of the Opus v.7.5 Library (particularly for PMMA). Obviously, the broad absorption peak at 3350 cm^{-1} is assigned to O–H stretching, attributed to hydroxyl groups from the cotton structure. The characteristic C=O stretching vibration that appears at 1745 cm^{-1} confirms the presence of ester and carbonyl groups from PMMA. Additionally, these include the asymmetric stretching of CH_3 at 2923 cm^{-1}, asymmetric and symmetric bonds of the methylene group (CH_2) at 2853 and 2923 cm^{-1}, carbonyl bond (C=O) at 1745 cm^{-1}, and the asymmetric stretching group of α-CH_3 at 1314 cm^{-1} and 1161 cm^{-1} carbonyl bond (C=O). All spectra had a resolution of 4 cm^{-1}.

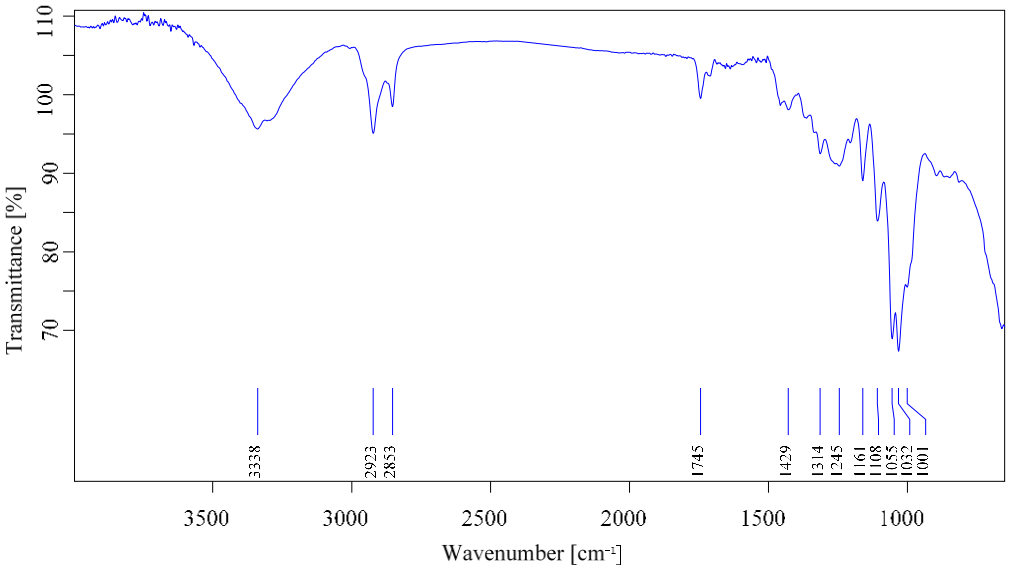


Figure 3. FTIR spectrum of sample OCP3 matches with Opus v.7.5 Library poly(methyl methacrylate).

3.3. DATA ANALYSIS

To estimate potential microplastic risks from mouthwash samples, it was calculated the following risk indices: *(i)* polymer risk index (H) for polypropylene and poly(methyl methacrylate), based on toxicity; *(ii)* daily plastic intake (DPI); *(iii)* estimated annual consumption from daily use of mouthwashes; *(iv)* chronic daily intake through ingestion (CDI_{ng}). Specifically, results for H, DPI, and CDI_{ng} indices for both adults and children are shown in Fig. 4.

The results for the H, DPI, and CDI_{ng} risk indices were multiplied by 1,000 to highlight them on the graph shown in Fig. 4. The polymer risk index (H) for the two samples in which MPs were identified (i.e., OCP_1 and OCP_3) was 200 for sample OCP_1, in which two polypropylene fibres were identified, and 1224 for sample OCP_3, where two polypropylene and a poly(methyl methacrylate) fibres were found. Lithner et al. [39] established five risk levels for different cosmetics. The analysed mouthwash samples fall into low (OCP_1) and high (OCP_3) risk levels, respectively. The daily plastic intake (DPI) was 160 $n \cdot d^{-1}$ for sample OCP_1 and 240 $n \cdot d^{-1}$ for sample OCP_3. In the study by Protyusha et al. [46] conducted on oral care products in India, the Daily Microplastic Emission (DME) from mouthwash is 74 billion particles$\cdot d^{-1}$, and in Romania, where the population in 2025 was 18,908,650 inhabitants according to INS data [47], the DPI is 378,173,000 MPs$\cdot d^{-1}$. The exposure route and risk

level of the polymers identified in the analyzed samples must be established before assessing the possible risk to human health, according to the indications provided by Loprieno N. [48].

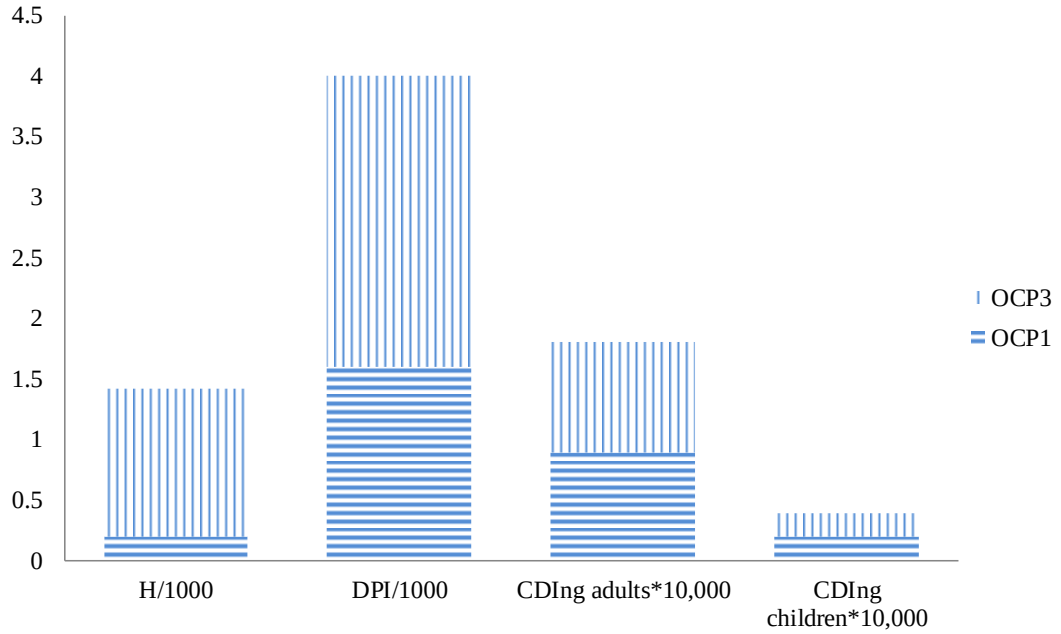


Figure 4. Graphical representation of calculated risk indices (polymer risk index, daily plastic intake, chronic daily intake through ingestion).

Chronic daily intake through ingestion (CDI_{ng}) calculated for adults and children was $9.14 \cdot 10^{-5}$, respectively $1.67 \cdot 10^{-5}$ for sample OCP_1 and $1.37 \cdot 10^{-4}$, respectively $2.50 \cdot 10^{-5}$ for sample OCP_3. In the study conducted by Banica et al. [38], five risk levels for CDI_{ng} were established, and samples OCP_1 and OCP_3 fall into a very high-risk level. Estimated annual consumption (EAI) was estimated for a mouthwash usage rate of 20 $mL \cdot d^{-1}$ to be 58,400 $MPs \cdot year^{-1}$ for sample OCP_1 and 87,600 $MPs \cdot year^{-1}$ for sample OCP_3. Annual Microplastics Exposure (AME) reported by Protyusha et al. [46] (AME = 22,338 $MPs \cdot year^{-1}$), which is equivalent to the EAI calculated in the present study, is 7.65 times higher for the OCP_1 sample, respectively, 5.1 times higher for the OCP_3 sample.

Taking into account the studies carried out by Protyusha et al. [46] and Saha et al. [49] which aimed to quantify MPs isolated in a wide range of oral care products, but also the study carried out by Aytulun et al. [50] carried out on toothbrushes, the number of MPs that enter the oral cavity following the use of care, cleaning and treatment products (e.g. toothpaste, mouthwash, tooth cleaning powder), but also of the objects used for the application of these products (e.g., toothbrush and dental floss), is worrying and even alarming due to the accumulation of MPs from the wide range of used products. Also, MPs accumulate in the oral cavity, which represents a significant proportion of the human body, and in wastewater treatment plants, these MPs cannot be filtered. Sun et al. [51] estimated that 1,500,000 MPs were released into wastewater treatment plants due to the use of personal care products, including oral care products.

4. CONCLUSIONS

Despite challenges in identifying microplastics, this research demonstrates that optical microscopy and micro-FTIR spectroscopy can accurately quantify and characterise them. These results align with previous studies [21-25]. Additionally, microplastic size plays a

crucial role in assessing health risks. Along with size, morphology is significant; for example, non-fibrous microplastics may pose lower toxicological risks than fibres. Moreover, visual assessment and mapping via microscopy (using optical and micro-FTIR techniques) can help determine potential microplastic sources. For instance, black, rubbery fragments likely originate from the atmosphere (e.g., tyre wear), textile fibres may be shed from clothing, and pellets may be deliberately added to cosmetics. On the other hand, this research investigates the presence of microplastics in mouthwash products and their potential risks to human health. The findings revealed an average concentration of 1100.00±532.92 microparticles·L^{-1}, with particle sizes ranging from < 50 μm (133.33±115.47 n·L^{-1}) to > 1000 μm (333.33±230.94 n·L^{-1}), with the abundant fibers in the range of 500-1000 μm (2133.33±305.51 n·L^{-1}).

The microplastics were found to have fibre shapes, including irregular and short, as well as filamentous and continuous, unbroken. Furthermore, 100% of the microparticles were coloured, in order blue > black > red > grey > turquoise. In terms of potential health risk indices (i.e. the polymer risk index for polypropylene and poly(methyl methacrylate), based on toxicity, daily plastic intake, estimated annual consumption from the daily use of mouthwashes, and chronic daily intake through ingestion), which were calculated for both the adult and children categories and compared with other research, it was found that the OCP_1 and OCP_3 samples fall into a very high-risk category.

REFERENCES

[1] Napper, A., Bakir, S. J., Rowland, R. C., *Marine Pollution Bulletin*, **99**(1–2), 178, 2015.
[2] Hernandez, L. M., Yousefi, N., Tufenkji, N., *Environmental Science and Technology Letters*, **4**(7), 280, 2017.
[3] Nasrabadi, A. E., Kabirinia, F., Bonyadi, Z., *Applied Water Science*, **15**, 19, 2025.
[4] Commission Regulation (EU) 2023/2055 of 25 September 2023 amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards synthetic polymer microparticles.
[5] Leslie, H., *IVM Institute for Environmental Studies*, **476**, 1, 2014.
[6] Wang, S., Zheng, N., Peng, L., An, Q., Chen, C., Wei, Y., *Ecotoxicology and Environmental Safety*, **302**, 118694, 2025.
[7] FDA, Code of Federal Regulations Title 21, Volume 3 Sec 184.1201 calcium glycerophosphate. 1992. Available from: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?fr=184.1201. Accessed on February 18, 2026.
[8] Glick, M., Williams, D. M., Kleinman, D. V., Vujicic, M., Watt, R. G., Weyant, R. J., *International Dental Journal*, **66**(6), 322, 2016.
[9] Kim, Y. R., Nam, S. H., *Antibiotics*, **11** (4), 488, 2022.
[10] Akula, S., Nagarathna, J., Srinath, K., *Frontiers Dent*, **18**, 32, 2021.
[11] Eley, B. M., *British Dental Journal*, **186**(6), 286, 1999.
[12] Netuschil, L., Weiger, R., Preisler, R., Brecx, M., *European Journal of Oral Sciences*, **103**(6), 355, 1995.
[13] Van der Weijden, F. A., Van der Sluijs, E., Ciancio, S. G., Slot, D. E., *Dental Clinics of North America*, **59**(4), 799, 2015.
[14] Yazicioglu, O., Ucuncu, M. K., Guven, K., *International Dental Journal*, **74**(2), 223, 2024.

[15] Yadav, P., Rani, M., Chaudhary, S., *Toxicology and Environmental Health Sciences*, **17**, 275, 2025.
[16] Leslie, H. A., van Velzen, M. J., Brandsma, S. H., Vethaak, A. D., Garcia-Vallejo, J. J., Lamoree, M. H., *Environment International*, **163**, 107199, 2022.
[17] Pironti, C., Notarstefano, V., Ricciardi, M., Motta, O., Giorgini, E., Montano, L., *Toxics*, **11** (1), 2013.
[18] Prata, J.C., da Costa, J.P., Lopes, I., Duarte, A.C., Rocha-Santos, T., *Sci. Total Environ*., **702**, 2020.
[19] Huang, S.M., Huang, X.X., Bi, R., et al., *Environ. Sci. Technol*., **56**(4), 2476–2486, 2022.
[20] Nawalage, N.S.K., Bellanthudawa, B.K.A., *Mar. Pollut. Bull.*, **182**, 2022.
[21] Bucur (Popa), R. M., Radulescu, C., Dulama, I. D., Stirbescu, R. M., Bucurica, I. A., Banica, A. L., Stanescu, S. G., *Toxics*, **13**(5), 354, 2025.
[22] Banica, A. L., Bucur (Popa), R. M., Dulama, I. D., Bucurica, I. A., Stirbescu, R. M., Radulescu, C., *Scientific Study and Research Chemistry and Chemical Engineering, Biotechnology, Food Industry*, **24**(2), 155, 2023.
[23] Bucur (Popa), R.M., Radulescu, C., Stirbescu, R. M., Banica, A. L., Bucurica, I. A., *UPB Scientific Bulletin, Series B: Chemistry and Materials Science*, **88**(1), 169, 2026.
[24] Stirbescu R. M., Radulescu C., Popa (Bucur) R. M., Banica A. L., Bucurica I. A., Dulama I. D., *Journal of Xenobiotics*, **16**(1), 37, 2026.
[25] Bucur (Popa) R.M., Stanescu S.G., Radulescu C., Banica A.L., Stirbescu R.M., *Journal of Science and Arts*, **25**(2), 415, 2025.
[26] Barnes, M., Sule-Suso, J., Millett, J., Roach, P., *Biology Letters*, **19**(3), 20220546, 2023.
[27] Chen, Y., Wen, D., Pei, J., Fei, Y., Ouyang, D., Zhang, H., Luo, Y., *Current Opinion in Environmental Science & Health*, **18**, 14, 2020.
[28] Karthik, R., Robin, R. S., Purvaja, R., Karthikeyan, V., Subbareddy, B., Balachandar, K., Hariharan, G., Ganguly, D., Samuel, V. D., Jinoj, T. P. S., Ramesh, R., *Environmental Pollution*, **305**, 119297, 2022.
[29] Veerasingam, M., Ranjani, R., Venkatachalapathy, A., Bagaev, V., Mukhanov, D., Litvinyuk, L., Verzhevskaia, L., Guganathan, P., *TrAC Trends in Analytical Chemistry*, **133**, 116071, 2020.
[30] ISO 14644-1:2015, *Cleanrooms and Associated Controlled Environments—Part 1*, Classification of Air Cleanliness by Particle Concentration. Second Edition. International Organization for Standardization: Geneva, Switzerland, 2015.
[31] Kutralam-Muniasamy, G., Shruti, V. C., Pérez-Guevara, F., Roy, P. D., Elizalde-Martínez, I., *Science of The Total Environment*, **875**, 162610, 2023.
[32] Shruti, V. C., Kutralam-Muniasamy, G., *Trends in Environmental Analytical Chemistry*, **38**, e00203, 2023.
[33] Banica, A. L., Radulescu, C., Dulama, I. D., Bucurica, I. A., Stirbescu, R. M., Stanescu, S. G., *Foods*, **13**(19), 3069, 2024.
[34] Zhang, X., Xia, M., Su, X., Yuan, P., Li, X., Zhou, C., Wan, Z., Zou, W., *Journal of Hazardous Materials*, **413**, 125321, 2021.
[35] Bikiaris, N., Nikolaos, N. F., Barmpalexis, P., *Cosmetics*, **11**(5), 145, 2024.
[36] Singh, A., Mishra, B. K., *Journal of Cleaner Production*, **427**, 139082, 2023.
[37] Habib, R. Z., Aldhanhani, J. A. K., Ali, A. H., Ghebremedhin, F., Elkashlan, M., Mesfun, M., Kittaneh, W., Al Kindi, R., Theimann, T., *Environmental Science and Pollution Research*, **29**, 89614-89624, **2022.**
[38] Banica, A. L., Radulescu, C., Buruleanu, C. L., Olteanu, R. L., Stirbescu, R. M., Stanescu, S. G., Dulama, I. D., *Microplastics*, **4**(4), 98, 2025.

[39] Lithner, D., Larsson, A., Dave, G., *Science of The Total Environment*, **409**(18), 3309, 2011.
[40] Binelli, A., Tognetto, M., Cremonesi, C., Torre, C. D., Caorsi, G., Magni, S., *Journal of Hazardous Materials*, **492**, 138052, 2025.
[41] Aydin, R. B., Yozukmaz, a., Sener, I., Temiz, F., Giannetto, D., *Life*, **13**(8), 1686, 2023.
[42] Aralu, C., Okoye, P., Abugu, H., Egbueri, J., Eze, V., *Journal of Hazardous Materials Advances*, **15**, 100442, 2024.
[43] Banica, A. L., Radulescu, C., Dulama, I. D., Bucurica, I. A., Stirbescu, R. M., Stanescu, S. G., *Journal of Science and Arts*, **24**(1), 223, 2024.
[44] Banica, A. L., Radulescu, R. M., Stirbescu, R. M., Dulama, I. D., Bucurica, I. A., Stanescu, S. G., Stirbescu, N. M., *U.P.B. Scientific Bulletin, Series B*, **86**(4), 85, 2024.
[45] Jung, M. R., Horgen, F. D., Orski, S. V., Rodriguez, C. V., Beers, K. L., Balazs, G. H., Jones, T. T., Work, T. M., Brignac, K. C., Royer, S. J., Hyrenbach, K. D., Jensen, B. A., Lynch, J. M., *Mar. Pollut. Bull.*, **127**, 704, 2018.
[46] Protyusha, G. B., Kavitha, B., Robin, R. S., Nithin, A., Ineyathendral, T. R., Shivani, S. S., Anandavelu, I., Sivasamy, S., Samuel, V. D., Purvaja, R., *Environmental Pollution*, **343**, 123118, 2024.
[47] National Institute of Statistics, Romania in Figures, 2025. Available from: https://insse.ro/cms/sites/default/files/field/publicatii/romania_in_cifre_2025.pdf
[48] Loprieno, N., *Food and Chemical Toxicology*, **30**, 809–815, 1992.
[49] Saha, U., Jena, S., Simnani, F. Z., Singh, D., Choudhury, A., Naser, S. S., Lenka, S. S., Kirti, A., Nandi, A., Sinha, A., Patro, S., Kujawska, M., Suar, M., Kaushik, N. K., Ghosh, A., Verma, S., *Ecotoxicology and Environmental Safety*, **290**, 117526, 2025.
[50] Aytulun, C. O., Dana, P. A., Gachayzade, Z., Gedik, K., Balci, N., Toygar, H., *Microchemical Journal*, **216**, 114680, 2025.
[51] Sun, Q., Ren, S. Y., Ni, H. G., *Science of The Total Environment*, **742**, 140218, 2020.