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Investigating the release of microplastics from tea bags into tea drinks and human exposure assessment

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Abstract

Background: The escalating production and utilization of plastics, driven by their distinctive properties, have significantly contributed to environmental pollution. One of these pollutants is microplastic (MP), which is present in many food products, such as tea bags. The primary objective of this study was to investigate the presence and characteristics of MPs in tea bags from five different brands in Iran.

Methods: For this study, 30 tea bags from five different brands in Iran were selected for sampling. The unaltered tea bags (with tea) were placed in 100 mL of ultrapure water at a temperature of 95 °C for 5 minutes, representing an alternative approach involving tea bag sampling with tea and without rinsing. Subsequently, the samples were subjected to quantitative analysis using a scanning electron microscope (SEM) and qualitative analysis using a micro-Raman spectrometer.

Results: All brands exhibited MP contamination, with an average abundance of 518 459 items per individual tea bag. Fibers were the predominant form of MPs, primarily falling within the 10–50 µm size range. Polymer analysis identified cellulose acetate (CA), nylon, polyethylene terephthalate (PET), and polyethylene (PE) as the prevalent types, with CA and nylon as the most frequent ones. The estimated daily intake (EDI) of MPs was calculated at approximately 17,282 items/kg-BW/day for children consuming 100 ml of tea daily and 14,813 items/kg-BW/day for adults consuming 400 mL of tea daily.

Conclusion: This study underscores tea bag consumption as a significant route of MP exposure for humans and the environment, posing potential risks and implications.

Keywords: Microscopy, Electron, Scanning, Tea, Plastics

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Introduction

The industrial-scale production of plastics began in the 1950s, and today, plastics constitute a vital and irreplaceable component of human life (1). Over time, the production and utilization of plastics have experienced a steady increase, driven by their advantageous characteristics such as high stability, lightweight structure, and flexibility, rendering them ideal for diverse applications (2).

Microplastics (MPs) represent a recently identified form of pollution, characterized by plastic particles with diameters ranging from 1 µm to less than 5 mm. The diverse forms of MPs, including fibers, foam, pellets, films, and fragments, underscore the complexity of this emerging environmental challenge (3). MPs are categorized into primary or secondary types based on their origin. Primary MPs, often found in granular forms, are prevalent in cosmetics, personal care products (lotions, soaps, scrubs, toothpaste, cleaning agents), and clothing fibers, contributing significantly to environmental contamination. The annual presence of primary MPs in the UK is estimated to range from 105 to 1054 tons, with an inadvertent release of 5-53 billion particles annually. In contrast, secondary MPs result from the unintentional breakdown of larger plastic items, generating irregularly shaped plastic fragments (4-6). The European continent discharges an annual estimated quantity of secondary MPs into the oceans, ranging from 68 500 to 275 000 tons, primarily due to degradation processes induced by environmental factors (3-5). Plastic containers, widely used in food packaging for their portability and durability, pose a potential risk of product contamination (7-10). Synthetic fibers, which make up 73% of global fiber usage, especially polyester, polyamide, acrylic, and polyolefin, are prevalent sources of MPs, given the extensive usage of these materials (3,11). The escalating global plastic consumption has led to the pervasive infiltration of MPs into the environment, necessitating comprehensive strategies to mitigate their impact.

MPs have been identified in a myriad of ecosystems, encompassing soil, oceans, rivers (12), lakes, urban runoff, water treatment by-products, sewage (13), and various consumer products (7,14-16). MPs have been documented in diverse environmental matrices, including bottled water (17), tap water (18), cold and energy drinks (19), table salt (20,21), fish larvae (22), fish (23), landfill leachates (24), indoor dusts (25), urban runoff (26), healthcare products (27), and personal protective equipment (28). The pervasive nature of MP contamination raises concerns about unintended human exposure through ingestion. It is estimated that an individual may ingest between 39 000 to 52 000 MPs annually (29).

The escalating use of plastic materials in food packaging has raised concerns regarding the potential release of MPs and nanoplastics (30). The plastic components used in consumer items can be broken into MPs and nanoplastics, making their identification and quantification challenging (31-33).

Tea bags, often constructed with plastic materials, can emit substantial quantities of MPs upon use (34-37). Tea bags frequently incorporate plastic materials in their packaging. Therefore, the packaging of commercial tea products can contribute to the presence of MPs. Hernandez et al demonstrated that a single tea bag releases approximately 11.6 billion and 3.1 billion nanoplastics composed of nylon and polyethylene terephthalate (PET) into one cup of tea (34). Tsochatzis et al and Busse et al have shown that monomers and oligomers can move from plastic polymers used in tea bags (e.g., PET and nylon). This indicates that teas can be contaminated by these substances, adding to the list of pollutants (38,39). An examination of different tea bag brands obtained from multiple supermarkets in Turkey showed that 4 out of 11 tea bags made for teacups contained plastic, whereas all 11 tea bags intended for teapots contained plastic. When tea bags are utilized in the preparation of hot beverages like tea, there is a possibility that the bag may contain plastic fibers, which may pose serious health risks (40). Afrin et al examined the potential existence of MP-like particles in tea bag samples from several brands collected in Dhaka, Bangladesh. All examined samples (consisting of five different brands) were found to be contaminated with MPs. The mean size of these contaminants ranged from 200.6 to 220.7 µm. Ultimately, it was observed that MPs originating from tea bags in Dhaka have the potential to generate an average emission of 10.9 million grams of MPs each year (36). The study conducted by Kashfi et al examined the quantity and characteristics of MPs and phthalate esters (PAEs) concentrations in 45 tea bag samples from various Persian and German brands. The number of MPs in the Persian and German tea bag samples was, on average, 412.32 and 147.28 items per single tea bag, respectively. The primary size range of MPs was associated with particles of 100–250 µm. Polyethylene (PE) and nylon were the predominant types of MP polymers (9). In addition, Xu et al and Mei et al (2022) did further research to quantify the levels of MPs present in tea bags (35,37).

Tea consumption is a tradition in many countries, and the majority of tea drinkers prefer using tea bags instead of loose tea leaves (36). Tea bag manufacturers utilize plastic materials in their production, which might result in the potential contamination of tea bags with MP particles. The emission of MPs from tea bags can lead to numerous health complications in humans. A high concentration of MPs in the human body can result in the development of inflammatory lesions, which in turn can contribute to a higher incidence of neurological illnesses, immunological disorders, and cancers (41).

In this study, an alternative approach was presented to investigate the emission of MPs from tea bags by using unaltered tea bags with tea and without rinsing. Previous research in this area has typically involved emptying tea bags and rinsing them multiple times before analysis. However, using unaltered tea bags with tea and without rinsing, the present study aimed to simulate real-world conditions more accurately and assess the magnitude of MP exposure in a more representative manner. This innovative methodology allows us to capture the potential release of MPs from tea bags into the environment during typical usage scenarios. By simulating the process of brewing tea without any alterations to the tea bags, we can better understand the actual levels of MP emissions and their impact on environmental contamination.

This study offers a more realistic assessment of MP exposure from tea bags compared to previous methods. By adopting this innovative methodology, we aimed to provide valuable insights into the extent of MP pollution associated with tea bags and contribute to a better understanding of this emerging environmental challenge.

Materials and Methods

Sample collection and sampling method

In the present study, samples were acquired in their original factory packaging to mitigate contamination risks, specifically targeting brands with a substantial market presence in Iran. We carefully selected five prominent tea bag brands for an extensive analysis. Our methodology was adapted from previous research with minor adjustments (36). Unlike earlier studies, unaltered tea bags (Tea bags with tea and without rinsing) were employed to faithfully simulate the release of MPs into the environment and assess the magnitude of MP exposure.

Each tea bag was immersed individually in 100 ml of ultrapure water at 95°C for 5 minutes in a glass beaker. After extraction, 20 mL of hydrogen peroxide was introduced to eliminate organic substances. The resultant mixture was isolated at room temperature for 3-4 hours, followed by filtration through PTFE filters (pore size 0.45 µm) via a vacuum pump. The filtrate was then isolated for drying. Each brand contributed six tea bags (total of 30 samples) to our sampling, with three designated for quantitative analysis (15 samples) through scanning electron microscope (SEM) and the remaining three for qualitative analysis (15 samples) using the UniRAM Raman spectrometer. While Afrin et al note potential alterations in MPs at 95 °C, this temperature was selected to emulate the common tea preparation practice, where consumers often use water nearing its boiling point (36).

Microplastic analysis

For qualitative assessments, a UniRAM Raman spectrometer (iDus, Andor, Oxford Instruments, UK) was employed. The spectrometer featured a solid-state laser with an excitation wavelength of 785 nm and a power output of 200 mW. From each PTFE filter, a cut-out measuring 1 × 1 cm was secured to an Au-coated glass holder. The Raman spectra were then acquired using surface-enhanced Raman spectroscopy. Five spectra were obtained from each cut-out, and the spectra were baseline-corrected using the Origin 2018 software. Subsequently, the spectra were compared with reference spectra to confirm the identification of the MPs.

SEM (TESCAN-Vega3, Czech) was utilized for investigation and imaging. A thin layer of conductive gold was applied to the filters before analysis. MP classification was based on size categories (10–50, 50–100, 100–250, 250–500, > 500), and morphological distribution (fiber and fragment) was determined. The exact measurements of each filter were obtained through SEM, and ImageJ software was employed for the size analysis of identified MPs. After analysis, the concentration of the MPs in each tea bag was determined by comparing the area of the cut-out filter to the total filter area. Corrections based on qualitative analysis and control samples were then applied to MP counts.

Human exposure

A rigorous risk assessment was conducted to determine the degree of human exposure to MPs. The estimated daily intake (EDI) of MPs was assessed across various age groups, including children, teenagers, and adults. The EDI was calculated using the following formula (42):

$$EDI = \frac{C \times DI \times EF \times ED}{BW \times AT}$$

In this equation, *C* represents the mean count of MPs determined in this study, *DI* refers to the daily intake of liquid (150–750 ml for children, 250–1500 mL for adults), and *EF* (day) represents exposure frequency, *ED* (year) is exposure duration, *AT* (day) is averaging time, and *BW* (kg) is body weight. The body weight (BW) number for children is 16, while for adults, it is 70. It is important to note that around 150–250 ml of tea is consumed per serving (9,43). The values of ED, EF, and AT were considered based on previous studies (44-46). The parameters utilized for computations are displayed in Table 1. Based on the guidelines from the European Food Safety Authority and the study by Kashfi et al., we considered three scenarios for tea consumption per person: 150, 250, and 750 mL for children, and 250, 1000, and 1500 mL for adults (9,47).

Statistical analysis

MP analysis of various tea bag brands was conducted using GraphPad Prism 10 and Microsoft Excel 2021 software. Descriptive statistics were employed to scrutinize the dataset, providing a comprehensive overview. Subsequently, the concentration of MPs in each brand was subjected to comparative analysis using a one-way ANOVA test ($P < 0.05$). Further insights were derived through a Tukey post-hoc test, facilitating in-depth comparisons between individual brands.

Quality control

This study employed strict methods to prevent sample contamination during the measurement of MPs in different tea brands. Glass containers were utilized to prevent sample contamination. Before use, all containers underwent acid washing and were rinsed three times with ultra-pure water. Sampling procedures were executed in a controlled environment with stringent isolation measures. Rigorous cleaning of tools and surfaces preceded each experiment, and aluminum foil coverage was maintained throughout all experiment phases to prevent contamination. Additionally, three control samples were incorporated, and the detected particle count in the control samples was subtracted from the overall MPs. Raman analysis discerned non-plastic particles in each brand, allowing adjustment of the total identified particles to exclusively represent MP particles.

Results

Microplastics abundance

This study conducted a systematic analysis of five distinct tea bag brands to investigate the presence of MPs and assess contamination levels. Remarkably, despite variations in brand origin and manufacturing processes, the statistical analysis revealed no statistically significant differences ($P > 0.05$) in the overall MP count among the tea bag brands examined (Figure 1). Although there were no significant differences in the overall MP count among brands, there were notable variations in the number of MPs within individual brands. Brand D displayed the

Table 1. Parameters used in human exposure

	DI (L/day)	BW (kg)	EF (day)	ED (year)	AT (day)	Scenario 1	Scenario 2	Scenario 3
Child	0.15-0.75	16	345	6	2070	0.15	0.25	0.75
Adult	0.25-1.5	70	345	30	10350	0.25	1	1.5

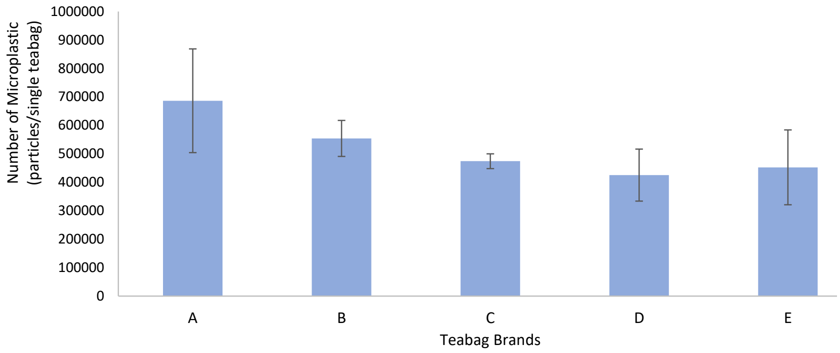

Figure 1. Mean and standard deviation of MPs in various tea bag brands

lowest MP abundance, with an average of 425 234 items per single tea bag, while brand A exhibited the highest abundance, totaling 686 496 items per single tea bag. Utilizing SEM imagery and Raman analysis data, particle quantification revealed an average of 518 459 ± 136 440 MP particles per tea bag.

Microplastics physical characteristics

This study meticulously classified MP particles identified in various tea bag brands into five size categories, as depicted in Figure 2A (10-50, 50-100, 100-250, 250-500, > 500 µm). The size distribution of the discovered MP particles ranged from 10 to 3200 µm, indicating the diverse range of MP sizes present in the samples, with 79% falling within the 10-50 µm range, 12% between 100-50 µm, 6% between 250-100 µm, 2% between 500-250 µm, and 1% exceeding 500 µm. Notably, the dominant size category was 10-50 µm, constituting 79% of the total MP count. Notably, the majority of MP particles fell within the 10-50 µm range, indicating the prevalence of smaller MPs in the tea bag samples (Figure 2B).

Additionally, Figure 3 illustrates the presence of MPs in various forms, offering insights into their composition and morphology. MPs were categorized into fibers, fragments, and films. Fibers constitute the majority at 74.67%, followed by fragments at 18.67% and films at 6.67% (Figure 3B). Figure 3A provides further insight into the composition of each brand, indicating that all brands contain fiber particles, with one brand exclusively featuring fibers. Fragment particles are present in three brands, surpassing the occurrence of film particles, which are evident in four brands. Figure 4 includes multiple images captured using SEM, which clearly depict the shape and dimensions of the particles.

Chemical composition

This study utilized Raman spectroscopy to analyze 75 spectra obtained from tea bag samples, enabling comprehensive characterization of their polymer composition. By comparing these spectra with reference data, the study identified several polymer types present in the tea bags, including cellulose acetate (CA), PE, nylon, and PET. Figure 5 shows the Raman spectrum for these identified MPs, highlighting the distinct peaks corresponding to each polymer type. Figure 6A illustrates the distribution of these polymer types across all brands, revealing varying percentages: 40% CA, 10% PE, 30% nylon, and 20% PET.

Additionally, Figure 6B provides a detailed breakdown of the polymer composition for each brand. Notably, all brands contained CA and nylon as the primary constituents, constituting the majority of the polymer content. PE was identified in three brands, reflecting a degree of variability in polymer composition among the samples. Moreover, PET was present in two brands, further contributing to the diversity of polymer types observed across the tea bag samples. These findings underscore the complex nature of MP pollution in tea bags and highlight the importance of understanding the diverse range of polymer materials involved.

Human exposure

This study provides a comprehensive analysis of the daily intake of MPs among different age groups, including children, and adults, by assessing the quantity of MPs present in various tea brands. Table 2 serves as a detailed reference, offering insights into the EDI across three distinct scenarios.

In scenario 1, children exhibit an EDI of 25 922 ± 5275 MPs/kg-BW/day, while in scenario 3, this value increases to 129 614 ± 26 375 MPs/kg-BW/day. Similarly, for adults, the EDI in scenario 1 is 9258 ± 1883 MPs/kg-BW/day, escalating to 55 549 ± 11 303 MPs/kg-BW/day in scenario 3.

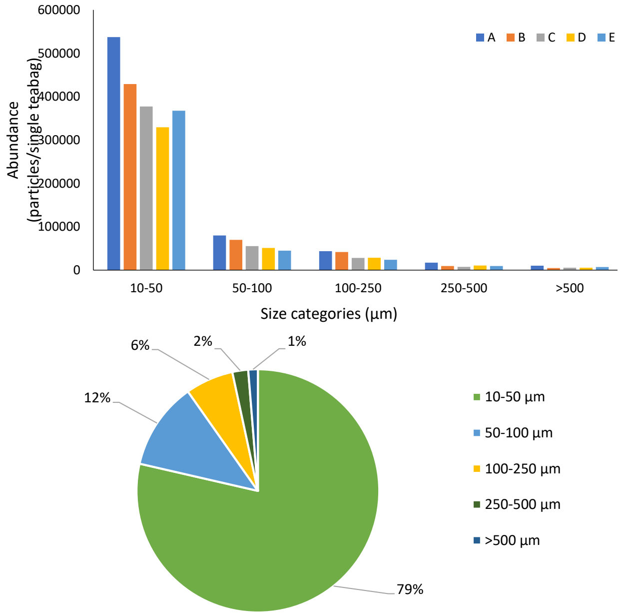

Figure 2. (A) The abundance of MPs in size categories in various tea bag brands, (B) Size distribution of identified MPs in tea bag samples

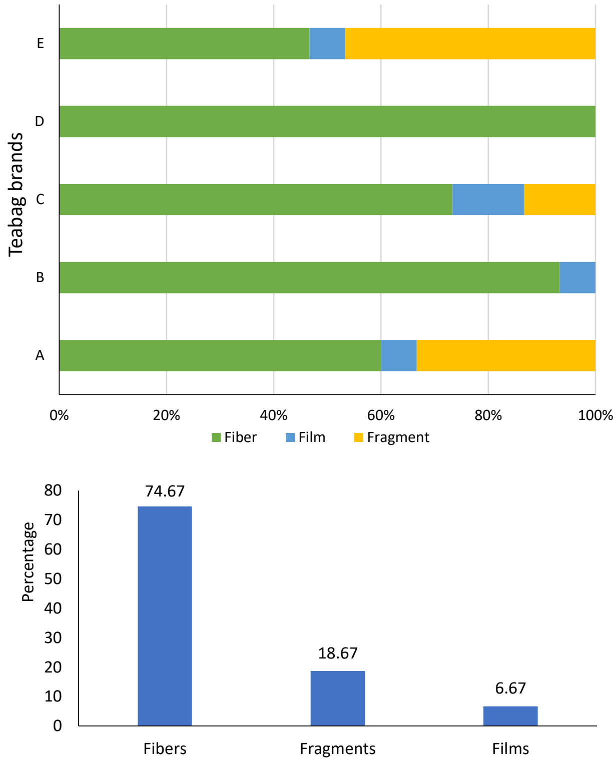

Figure 3. (A) The abundance of MPs categorized by shape in various tea bag brands, (B) Percentage distribution of identified MP shapes

Discussion

The findings of this study reveal significant insights into the presence, characteristics, and potential implications of MP contamination in tea bags, with important consequences for human health and environmental sustainability.

Microplastics abundance

The present study explores the variability in MP abundance compared to previous research, underscoring the impact of diverse sampling methodologies. Unlike prior investigations that often reported MP levels based on particles captured by bag filters (Table 3) (9,34,48), our study uniquely focuses on MPs emitted directly from unaltered tea bags (with tea and without rinsing). This approach offers a more comprehensive understanding of MP contamination in tea products.

In a research conducted by Kashfi et al, it was observed that the average abundance of MPs in Iranian tea bags was approximately 412 (9). However, our investigation yielded conflicting results. Kashfi et al. employed a sampling technique that involved cutting the tea bags and removing the tea leaves, followed by triple rinsing of the emptied tea bags. This methodology is similar to the one used by Hernandez et al. in their tea bag sampling approach, which has also been adopted by several other studies (34). Under this sampling framework, only the MPs released from the emptied tea bags during brewing are measured. In contrast, the present study focused on the MP content encountered by consumers during tea consumption, which could originate from various sources, thereby broadening the research scope beyond mere emissions during brewing.

For instance, Afrin et al reported a 22.2% higher MP content in intact tea bags (tea bags with tea and rinsed three times) compared to cut tea bags (tea bags without tea and rinsed three times), suggesting that the sampling method can significantly affect MP abundance (36). Similarly, Hernandez et al observed a significantly higher MP count, possibly due to the examination of plastic tea bags, contrasting with the paper tea bags utilized in the present study (34). This study unveiled a noteworthy volume of MPs released during human consumption of tea bags. Given the minimal MP release observed from tea bag filters in previous studies, the findings of this study strongly suggest the existence of alternative pathways through which MPs permeate tea bags.

Discrepancies in MP release from tea bags into tea infusions may be attributed to the diverse plastic materials used in tea bag packaging. Tsochatzis et al noted that tea bags are commonly housed in paper containers with plastic layers or internal plastic bags, which may facilitate MP attachment during the packaging process (38). Additionally, factors such as plastic packaging degradation and production procedures can contribute to variability in MP abundance (10,48). The presence of MPs in tea bags is likely influenced by various factors, including packaging type, production procedures, tea leaf origin, and the filter type of tea bags. Future studies should consider these factors to obtain a more comprehensive understanding of MP contamination in tea products.

Microplastics physical characteristic

In the present study, the size distribution of MPs in tea

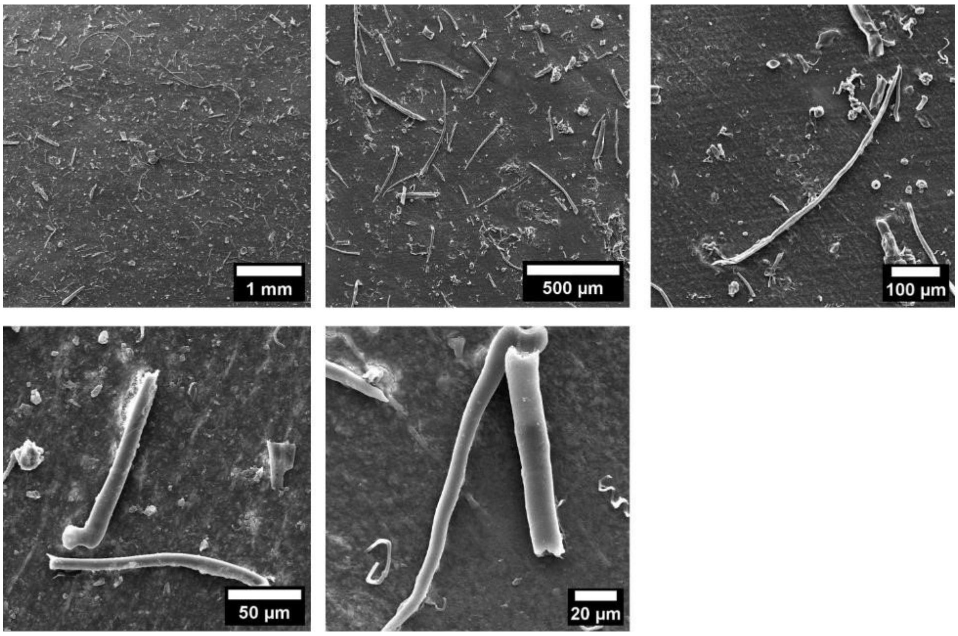

Figure 4. SEM images at different magnifications show the morphology of the MP-like particles in the samples after filtration

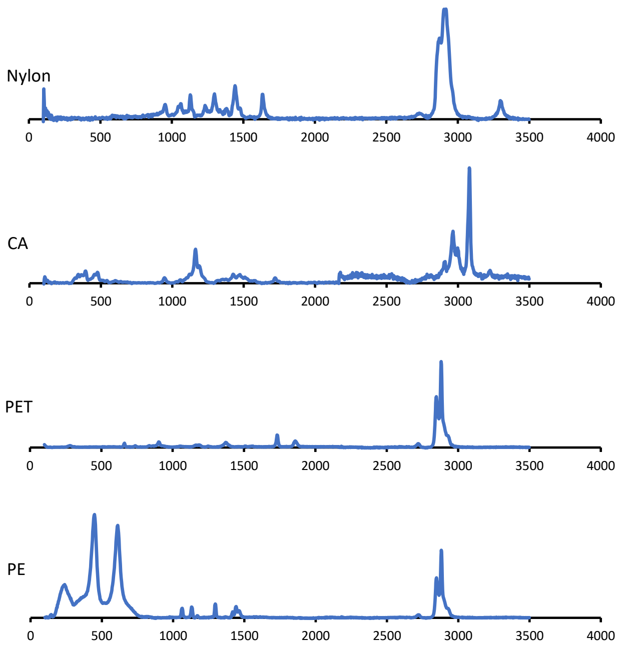

Figure 5. Raman spectrum of identified MPs from various brands of tea bags

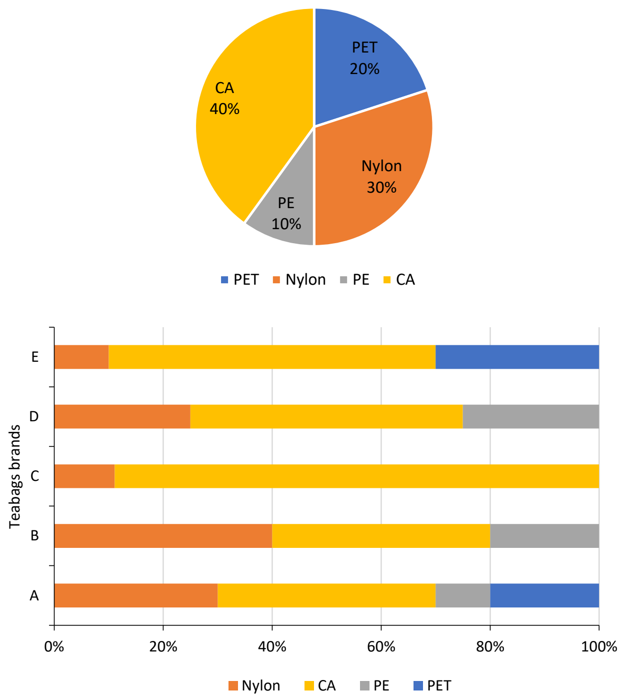

Figure 6. (A) Percentage of detected MPs polymer composition. (B) MPs composition in various tea bag brands

bags was investigated and compared with the results of previous research, particularly a study conducted in Bangladesh (36). The obtained results differed from those of Kashfi et al, which may be attributed to the differences in sampling methodology. Kashfi et al. separated smaller particles through tea bag emptying and rinsing before sampling, potentially affecting the observed size distribution (9).

In the majority of prior investigations, the primary morphology observed for the particles was fiber-shaped, a trend that aligns with the results of the present study (9,34,36,49,50). SEM images revealed a predominance of particles in the 10-50 micrometer range, which is consistent with prevalent patterns observed in various studies (36). However, a study in China reported a distinct size category of 620–840 µm for MPs in tea bag samples. This disparity in size distribution may be influenced by factors such as water temperature and transportation mechanisms during tea production (51).

According to the study of Jadhav et al, the reduction in size of MPs increases their surface area, leading to an

Table 2. Comparative evaluation of EDI of MPs with concentration (items/Kg-BW/day)

		Child			Adults		
		Sce 1	Sce 2	Sce 3	Sce 1	Sce 2	Sce 3
Items/kg-BW/day	Mean	25922.99	43204.99	129614.96	9258.21	37032.85	55549.27
	SD	5275.05	8791.74	26375.23	1883.95	7535.78	11303.67

Sce = Scenario.

Table 3. Levels and characteristics of MPs in tea bags, tea leaves, and tea infusions reported worldwide

Study area (n = sample number)	Sample type	MPs Abundance	Unit	Dominant size range (µm)	Major shapes	MPs Weight (mg)/tea bag	Major polymer types	Ref.
Bangladesh (n = 5)	Intact tea bag	≈50	Items/kg	23–60	Fiber	2.95-10.03	ABS[1]	(36)
	Tea bag	≈65	Items/kg	23–60	Fiber		EVA[2]	
Canada (n = 4)	Tea bag	≈11.6	Billion items/one cup	1-150	Fiber	-	Nylon	(34)
Ireland (n = 6)	Tea bag	-	-	951–2496	-	-	PP[3]	(35)
South Korea (n = 6)	Tea bag	-	-	-	Fiber	-	Nylon	(49)
Mexico City (n = 4)	Cold tea	11	Items/L	100-500	Fiber	-	Nylon	(19)
China	Tea bag	-	-	620–840	Fragment	-	PET[4], PP	(37)
China (n = 4)	Tea leave	200-500	Items/g	-	Fiber	-	PE[5], PET	(50)
Iran (n = 30)	Tea bag	412.32	Items/single tea bag	100–250	Fiber	-	Nylon, PE	(9)
Germany (n = 15)	Tea bag	147.28	Items/single tea bag	100–250	Fiber	-	Nylon, PE	
Iran (n = 15)	Tea bag	≈518000	Items/single tea bag	10-50	Fiber	-	CA[6], Nylon	This study

Abbreviations: ABS, Acrylonitrile butadiene styrene; EVA, Ethylene-vinyl acetate; PP, Polypropylene; PET Polyethylene terephthalate; PE, Polyethylene, CA Cellulose acetate.
Note: This table has been extracted from the study conducted by Kashfi et al. and made a few modifications (9).

increase in their potential for reactivity and deterioration (10). This highlights the importance of understanding the physical characteristics of MPs in tea bags, as smaller particles pose a higher risk due to their increased surface area.

Types of polymers

The present study identified various polymers present in tea bags, including CA, PE, nylon, and PET. These findings are consistent with previous research by Kashfi et al and Afrin et al. (2022), which also reported the presence of PE, nylon, and PET in tea bags (36). However, our study uniquely identified CA as a prevalent polymer, suggesting potential variations in tea bag composition across different regions and brands.

Raman spectroscopy was employed in our study to identify CA, PET, PE, and nylon, providing valuable insights into the chemical composition of MPs in tea bags. This contrasts with the approach used by Kashfi et al, who specifically investigated polymers extracted from tea bags after being cut and emptied. The findings of our study suggest that MPs may be introduced into tea bags during the production and packaging stages, contributing to the observed polymer composition (37). CA is a biodegradable polymer, and its presence in the tea bags may be related to the tea bag's composition.

Mei et al reported PET and polypropylene as the most frequent polymer types found in tea bags in China, highlighting potential regional variations in tea bag composition (37). Additionally, Hernandez et al identified nylon and PET as the most frequent polymer types, with nylon tea bags beginning to degrade in hot water, releasing particles into the tea infusion. These findings underscore the importance of understanding the degradation behavior of tea bag polymers and their implications for MP release (34).

Furthermore, a study conducted in China in 2022 investigated the presence of MPs in tea beverages, identifying PE and PET as the predominant plastic particles (50). These materials are commonly used for packaging by manufacturers in the food industry, suggesting potential contamination pathways from packaging materials to food products (19). Membrane filters employed in the industrial manufacturing of food products may also release additional amounts of MPs, further contributing to environmental contamination (52).

Overall, the findings of the present study contribute to the understanding of the types of polymers present in tea bags and their potential sources, highlighting the need for further research to elucidate the mechanisms of MP introduction and release from tea bag materials.

Human exposure

Our study conducted a comprehensive assessment to determine the daily intake of MPs among various age groups, including children and adults, at different consumption levels in Table 2. The EDI of MPs was calculated for three distinct scenarios, ranging from minimum to maximum tea daily intake across two groups.

The results presented in Table 2 indicate a wide range of EDI for children, varying from 25 922 to 129 614 (items/kg-BW/day) when consuming 150–750 mL of tea, based on the average number of MPs in each brand. Among the different age groups, children exhibit the highest EDI values, reaching up to 129 614 items/kg-BW/day. In scenario 1, characterized by the lowest consumption, the EDI for children surpasses adults due to their lower body weight ratio, indicating a significantly higher risk for this population.

Kashfi et al reported a narrower range of EDI for children, ranging from 22.68 to 113.38 items/kg-BW/day, which may be attributed to the differences in sampling methodology (37). Additionally, an investigation conducted in Bangladesh reported an average annual emission of MPs at 10.9 million grams per year, underscoring the significant environmental impact of MPs originating from tea bags (37). Interestingly, the quantity of MPs detected in milk, as reported in other studies, is lower than the levels observed in studies related to tea bags, highlighting the potential health risks associated with tea bag consumption (52-54).

These findings underscore the importance of further research to evaluate the long-term health implications of MP exposure through tea consumption and the development of regulatory measures to mitigate potential risks to human health.

Study limitations and suggestions

Sampling size and scope: While our study encompassed a diverse range of tea bag brands and sources, the sample size may not fully represent the entire tea bag market. Future studies with larger sample sizes and broader geographical coverage could provide a more comprehensive understanding of MP contamination in tea bags.

Detection methods: Despite employing meticulous sample analysis techniques, it is important to acknowledge that the detection and quantification of MPs in tea bags may be influenced by the sensitivity and limitations of the analytical methods used. Improvements in detection technology and standardized protocols could enhance the accuracy and reliability of future studies.

Limited characterization of microplastic types: While the present study identified predominant MP constituents in tea bags, including CA, PE, nylon, and PET, a more detailed characterization of MP types and sources could provide valuable insights into their origins and potential pathways of exposure.

Human exposure: Although the present study aimed to quantify human and environmental exposure to MPs through tea consumption, it is important to acknowledge the inherent uncertainties and assumptions associated with risk modeling. Future research incorporating real-world exposure data and epidemiological studies could refine our understanding of the health and environmental implications of MP contamination in tea bags.

Regulatory considerations: While this study highlights the urgent need for regulatory measures to mitigate the risks of MP pollution, it is important to recognize the complexities and challenges associated with implementing effective regulatory frameworks. Further research and stakeholder engagement are essential to inform evidence-based policy development and regulatory action in addressing MP contamination in the tea industry.

Despite these limitations, this study provides valuable insights into the prevalence and implications of MP contamination in tea bags, underscoring the importance of continued research efforts and proactive regulatory interventions to safeguard human health and environmental integrity.

Conclusion

In previous studies, the assessment solely focused on quantifying MP release from tea bag filters. In contrast, the present study investigated MP exposure to humans during tea consumption from tea bags. The findings indicate a notable release of MPs from tea bags. By comparing these outcomes with those of prior studies, it is apparent that these MPs infiltrated the tea bags from alternative sources.

Through meticulous sample analysis, we observed MP counts ranging from 425,234 to 686,496 per tea bag, with an average of 518,459 ± 136,440 MPs. Notably, MPs in the 10-50 µm size range were predominant (79%), with major constituents including CA (40%), PE (10%), nylon (30%), and PET (20%).

The present study identified key factors influencing MP release from tea bags, shedding light on the importance of understanding the sources of MP contamination in tea bag production and packaging processes. Furthermore, the risk assessment aimed to quantify the extent of human and environmental MP exposure resulting from tea consumption, underscoring the need for continued ecological research in this area.

Given the potential adverse effects of MP pollution on human health and the environment, regulatory measures are urgently needed to mitigate these risks. The present study emphasizes the critical role of sustained research efforts and proactive regulatory action in safeguarding human health and environmental integrity against the detrimental impacts of MP contamination. By raising awareness and advocating for effective regulatory interventions, we can collectively address the pressing issue of MP pollution and work towards a healthier and more sustainable future.

Future recommendations

To address the issue of MP contamination in tea bags, several recommendations are proposed:

Regulatory agencies should establish limits for MP contamination in food and beverage products, conduct regular monitoring of MP levels in tea bags, and enforce stringent quality control measures throughout the supply chain.

Consumer awareness initiatives should be implemented to raise awareness about the potential risks of MP exposure through tea consumption and promote sustainable alternatives such as loose-leaf tea.

Future research should focus on elucidating the sources and pathways of MP contamination in tea bags, conducting longitudinal studies to assess temporal trends, and evaluating the effectiveness of regulatory interventions in mitigating MP pollution.

Collaboration among researchers from diverse disciplines such as toxicology, epidemiology, and environmental science is essential to fully understand the health and environmental implications of MP exposure.

Overall, addressing the issue of MP contamination in tea bags requires a comprehensive approach involving regulatory action, consumer education, and scientific research. By implementing proactive measures and conducting further studies, we can mitigate the potential risks posed by MPs and work towards a healthier and more sustainable future.

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Competing interests

The author(s) declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

Ethical issues

The project study mentioned in this article has undergone ethical evaluation at Isfahan University of Medical Sciences (Ethical code: IR.MUI.RESEARCH.REC.1401.331). The authors confirm their agreement for the publication of this article.

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