Technical Report

APPROVED: 15 October 2025
doi: 10.2903/sp.efsa.2025.EN-9733

efsa SUPPORTING PUBLICATIONS

Literature review on micro- and nanoplastic release from food contact materials during their use

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Abstract

To search for evidence of micro- and nanoplastics (MNP) release during the uses of food contact materials (FCM), a structured literature review was carried out on studies published between 2015 and 20th January 2025. It identified 1711 publications of which 122 were selected for data extraction. Eight additional publications were added to provide more context. Most studies concern microplastics, while data on nanoplastics are almost entirely absent. Most publications use water or aqueous food simulants as FCM contact medium for suspension and subsequent isolation of released MNP. Foods other than mineral water were tested in only few cases. Despite the large number of publications investigating the release of MNP from FCM, the available evidence concerning the characteristics and quantities of released MNP from FCM remains limited. Many publications are affected by methodological shortcomings in test conditions, in sample preparation, and by deficiencies in the reliability of analytical data, with the consequence of frequent misidentification and miscounting. Based on the findings on release mechanisms, contaminations, mimicking substances, particle numbers and masses generated during the use of FCMs, it is concluded that (i) there is evidence of microplastics released during the uses of FCM, (ii) this release is due to mechanical stress, such as abrasion or friction, or due to materials with open or fibrous structures, (iii) despite the uncertainties, the actual release is much lower than the results presented in many publications. In view of all this, there is no sufficient basis at this stage to estimate MNP exposure from FCM during their uses. This review identifies methodological shortcomings and data gaps, and makes recommendations on related future research needs.

Keywords: Food Contact Materials (FCM), Microplastics, Nanoplastics, Release, Mechanism, Analysis, Contamination, Solubility, Use

Requestor: EFSA internal mandate

Question number: EFSA-Q-2025-00139

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Acknowledgements: EFSA wishes to thank the following for the support provided to this scientific output: Sandra Rainieri and Valeriu Curtui for their review.

Suggested citation: EFSA (European Food Safety Authority), Barthélémy E, Cariou R, Castle L, Crebelli R, Di Consiglio E, Hemy Dumas T, Franz R, Grog K, Lambré C, Lampi E, Milana MR, Munoz Guajardo I, Pronk M, Rivière G, da Silva M, Tietz T, Tsochatzis E, Van Hoeck E, 2025. Literature review on micro- and nanoplastic release from food contact materials during their use. EFSA supporting publication 2025: EN-9733. 53 pp. doi:10.2903/sp.efsa.2025.EN-9733

ISSN: 2397-8325

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1 Introduction

1.1 Background

Scientific interest in micro- and nanoplastics (MNP) has grown substantially due to their widespread environmental presence, their potential health risks and the challenges associated with their detection. In this context, EFSA convened Scientific Colloquium 25 (EFSA, 6–7 May 2021) to map priorities for assessing the human health risks of MNP in food. The discussions and available evidence were largely oriented toward environmental and dietary exposure particularly via seafood, drinking water and air deposition, rather than food contact materials (FCM) specific release[1]. However, the colloquium explicitly flagged FCM pathways as key knowledge gaps and priorities. Participants highlighted the need for harmonised definitions, reference materials and prioritised exposure-related gaps. Those gaps concern several areas: generating exposure data across the whole diet (including food packaging), identifying the main food items contributing to exposure and accumulation, and assessing the role of food-processing technologies in occurrence. They also include tracing the fate of microplastics (MP) and nanoplastics (NP) in the environment to anticipate foreseeable exposure routes, and developing standardised toxicological approaches to characterise bioavailability, bioaccumulation, and adverse effects associated with ingestion. It was underlined that total dietary exposure should integrate sources from farm to fork, including potential leaching/release from FCM. The relative importance of the pathways remains uncertain and warrants further investigation. As highlighted during the colloquium, one of the emerging concerns was the release of MNP from virgin and recycled plastic FCM into food.

While the concept of MNP migration as a diffusion-driven process remains questionable, the EFSA FCM Working Group (WG) and the EFSA Member State FCM Network recently reviewed and discussed several publications that were given media attention and scientific interest (e.g. Qian et al., 2024; Milne et al., 2024; Gerhard et al., 2022; Hernandez et al., 2019). Both the FCM WG and the FCM Network concurred that current knowledge and data on the release of MP and NP from FCM during their use remain limited. The FCM WG identified the need for periodic monitoring of the scientific literature.

1.2 Terms of reference

To shed light on this topic, as an initial step, EFSA agreed on a self-mandate with the objective to prepare a technical report containing an overview of the data currently available on: (i) the potential release of MP and NP from virgin and recycled plastic FCM; (ii) the mechanism of formation and degradation of MP and NP in FCM, and (iii) the data and methodological gaps that need to be addressed.

The FCM WG will be regularly consulted on the methodology, progress, and results, and will review the technical report. The report should serve as a basis to understand the magnitude and relevance of MP and NP release from FCM.

This report does not aim to assess the hazard properties of MP and NP and their safety after release from plastic FCM.

1.3 Interpretation of the terms of reference, terminology and boundaries

MP and NP are generally understood as solid plastic fragments resulting from the degradation or mechanical wear of larger plastic materials. In the context of FCM, such

1 In this report, release is meant as a transfer of substances or particles from the FCM to the food in contact and that does not involve diffusion into the polymer.

particles could in theory be generated by deterioration of the FCM surface due to physical forces (e.g. friction, abrasion), to aging (e.g. by air/oxidation, heat, UV/light), and/or to chemical interactions (e.g. swelling), during the manufacture and use of plastic FCM. These particles are typically irregular in shape and are expected to retain the chemical composition of the parent FCM, including both the polymer matrix and any incorporated additives.

By release of MP and NP from FCM during their use, it is understood both (i) the generation/production of MNP and (ii) the transfer from the FCM to the food of newly generated or existing MNP, for instance any stuck to the surface by electrostatic forces (the FCM acting as a carrier). The already existing MNP may originate from the production and handling processes of the FCM, from other contamination/pick-up sources, etc.[2] The use of the FCM is understood as the intended and/or the foreseeable contact with food(s).

It is important to differentiate MNP, which are defined as plastics, from additives, oligomers and other chemicals which are defined as low/lower-molecular-weight organic substances that are used or are formed during polymer synthesis. These organic chemicals may precipitate as particles under certain conditions; however, they are chemically distinct and are not considered as MP or NP because they are not fragments of plastic and do not share the same physical, chemical or structural features as MNP. Plastic additives and starting substances intended to be used in the manufacture of plastics are regulated at the EU level and they shall be assessed by EFSA prior to their authorisation by the European Commission (Regulation (EC) No 10/2011 on plastics[3]). Oligomers used as additives or formed from the regulated starting substances, should also be assessed. The assessment of any of these regulated chemicals that are in particulate form should also take into consideration the EFSA "Guidance on technical requirements for regulated food and feed product applications to establish the presence of small particles including nanoparticles" (EFSA Scientific Committee, 2021a). This guidance document aims at assessing the presence of a fraction of small particles and outlines appraisal criteria to confirm whether the conventional risk assessment of additives, oligomers etc. should be complemented with nano-specific considerations.

Regarding size, the EFSA Panel on Contaminants in the Food Chain (CONTAM Panel, 2016) defined MP as particles ranging from 0.1 to 5,000 µm, and NP as particles from approximately 1 to 100 nm (i.e., 0.001–0.1 µm). Although this definition was initially proposed in the context of environmental exposure and fate, it is used in the present report for consistency. It is nevertheless acknowledged that the upper size limit of 5,000 µm is - in the context of the potential release of NP and MP - much too high, representing rather visible macroplastics and very likely covered by the Hazard analysis and critical control points (HACCP), therefore they were not considered in this report.

1.4 Previous EFSA FCM activities

As a starting point, the activities of the EFSA WG on FCM and of the EFSA Member States FCM Network on the potential release of MP and NP from FCM during their use, were

[2] The particles not of the same essential polymer composition as the studied materials and articles are not the focus of this report.

[3] Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food. OJ L 12, 15.1.2011, p. 1–89.

reviewed[4]. This preliminary work served to guide the scope and direction of the present technical report.

Overall, the design and findings of the reviewed studies did not clearly demonstrate whether the particles reported actually originated from the FCM or from other sources, and whether all of these particles were even MP or NP. Instead, alternative sources such as dust or background contamination during sample handling and preparation as well as analytical interferences and artefact formation, could explain the observed findings and provide false positives, questioning overall the reliability of the reported results. In light of these uncertainties, the FCM WG identified the need for occasional monitoring of the literature and the FCM Network highlighted the need for targeted experimental studies under realistic use conditions, supported by robust analytical techniques, to enable a more accurate assessment of any possible consumer exposure.

A more complete description of the findings of this preliminary work, along with reference to the associated documents is given in Appendix A.

2 Data and Methodology

A structured literature review was carried out applying EFSA's systematic review methodology (EFSA Guidance on Application of systematic review methodology to food and feed safety assessments, 2010) with the exception of the formal assessment of methodological quality[5]). Details of the methodology are provided in Appendix B (eligibility criteria, literature identification, study selection, and data extraction). For clarity, only the research framework with the main question and sub-questions is reported in Table 1. This framework guided the identification of key features in the literature that align with the broader scope of the study.

The main questions were: is there evidence of MP/NP release from FCM during their use? If so, what are their characteristics?

Table 1. Sub-Questions to Address the Main Question

Theme	Sub-question (SQ)	Purpose
FCM types and test conditions	SQ1 – What types of FCM have been studied to evaluate whether they release MP or NP, under which conditions, and how representative are these conditions?	Identify the diversity of FCM tested and assess the relevance of experimental conditions.
Analytical methods and particle characteristics	SQ2 – What analytical techniques are used to detect and quantify MP/NP released from FCM, and what are the key characteristics of these particles (e.g. size, shape, composition)?	Evaluate the reliability and scope of analytical methods and reported particle features.
Contamination and carry-over	SQ3 – Are the particles released from FCM potentially from cross-contamination (e.g. air, sampling), food carry-over or	Distinguish true release from external

[4] FCM WG in March 2024 (45th meeting) and FIP FCM Network (7th meeting in 2019 and 8th in 2022).

[5] According to the EFSA guidance (2010): Assessment of methodological quality involves using tools (e.g. checklists) to identify those aspects of study design, execution, or analysis which induce a possible risk of bias.

	manufacturing process, and are they consistent with FCM composition?	contamination or artefacts.
False positives / mimicking substances	SQ4 – Can certain substances (e.g. oligomers precipitate, fatty acids) mimic MP/NP, and how do they impact the interpretation of release data?	Understand sources of misinterpretation and their implications for study validity.
Release mechanisms and influencing factors	SQ5 – What mechanisms drive the release of MP/NP, and how do food type, material ageing, or interactions affect this release?	Identify how release occurs and what factors accelerate or influence it.
Recycled materials	SQ6 – Is there evidence of MP/NP release from mechanically recycled materials, and does recycling influence their release?	Determine whether and how recycling affects MNP release from FCM.

The literature search, applied on publications between 1st January 2015 and 20th January 2025, identified 1711 publications. Following title-and-abstract screening and full-text screening, 122 publications were selected for data extraction. Of these, 81 were amenable to structured extraction using a dedicated DistillerSR software form (version 2025.5). Eight publications not retrieved by the literature search or beyond the deadline of 20th January 2025 were added manually during drafting of the report to provide additional context and background information (see Appendix B.5).

3 Assessment/Result

3.1 Generic workflow

Figure 1Figure 1: Generic workflow for the analysis of the MNP shows the generic workflow as a sequence of five typical methodological steps which were entirely or partly reported across the publications considered in this report for assessing the potential release of MNP from FCM. Despite substantial variability in experimental setups (e.g. direct analysis of food products versus tests using food simulants, various pre-treatments, or stress conditions such as heating, UV exposure, or agitation), most studies followed a similar analytical logic. This includes (i) acquisition and conditioning of the FCM samples[6], (ii) isolation (e.g. by membrane filtration) of particles from the food or simulant, (iii) detection and counting to estimate particle concentration, (iv) basic characterization of physical/morphological properties (essentially size, shape, colour), and (v) polymer identification using spectroscopic or mass-based techniques.

[6] A sample is a type of FCM articles (e.g. a bottle) considered in a publication. It does not count the total number of materials and articles that have been tested (e.g. replication of the test).

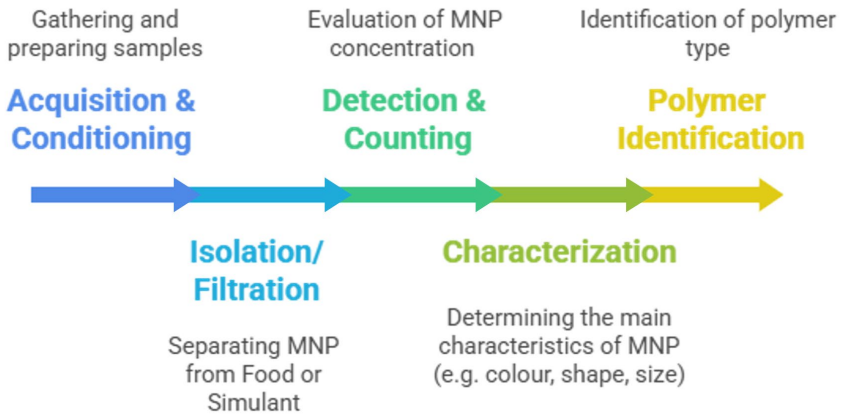

Figure 1: Generic workflow for the analysis of the MNP

In many cases only a subset of these steps was applied, e.g. proceeding only to particle detection and counting, or combining the initial sample preparation with direct polymer identification.

3.2 What types of FCM have been studied to evaluate whether they release MP or NP, under which conditions, and how representative are these conditions (SQ1)?

A total of 101 FCM samples were evaluated across 81 scientific publications (see Appendix C) investigating the potential presence of MP and NP. These FCM samples were purchased at retails and included commonly used materials and articles such as bottles and screw closures (e.g. Braun et al., 2021; Gambino et al., 2023; Gerhard et al., 2022; Giese et al., 2021), plastic food containers (mostly bowl and boxes for takeaway or not, microwavable or not, e.g. Li et al., 2022; Pallavera et al., 2024; Wang et al., 2023a), cups (e.g. Guo et al., 2024; Lee et al., 2024; Wang et al., 2023b; Yang et al., 2023) tea bags (Sakanupongkul et al., 2024; Yang et al., 2024; Banaei et al., 2024; Banaei et al., 2023) and plastic bags (e.g. plastic pouch, Ziploc® bag; Wang et al., 2023b; Dessí et al., 2021; Fang et al., 2024; Hee et al., 2022) which are frequently encountered in domestic and industrial food uses. The distribution of the types of FCM studied is shown in Figure 2[7], highlighting the predominance of bottles and closures (36 publications), followed by plastic food containers (20 publications), cups (15 publications), tea bags (15 publications), and plastic bags (8 publications), with other items (7) such as films, carton brick, kettles, mixing bowls, and grinding mills investigated only occasionally.

[7] The figure includes only the FCM types identified in the literature review. Those identified in the additional papers (see Appendix B.5) such as the two on cutting boards are not reported in the figure.

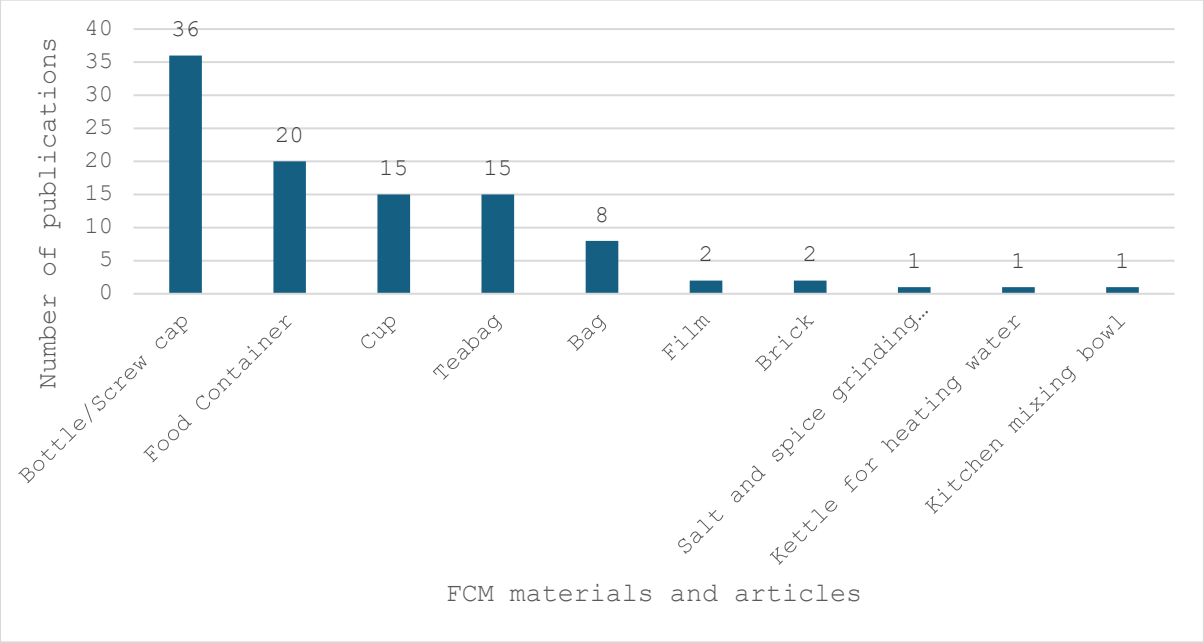

Figure 2: Frequency of FCM types across publications (based on 101 FCM reported in 81 publications; a single publication may address multiple FCM)

In terms of composition, a wide range of polymer types was covered across the reviewed studies. The most frequently investigated ones were polyethylene terephthalate (PET) (40 reported[8]), polyethylene types such as polyethylene (PE), high-density polyethylene (HDPE), and low-density polyethylene (LDPE) (40 reported), polypropylene (PP, 35 reported), and expanded polystyrene (EPS) (5 reported) reflecting their widespread use in the most frequently studied samples. Other polystyrene (PS), styrene–acrylonitrile (SAN), acrylonitrile–butadiene–styrene (ABS) (14 reported), polyamide/nylon (PA/Nylon) (8 reported), and polylactic acid (PLA) (6 reported) were less frequently studied. Non-plastic materials including cellulose (4 reported) and glass (6 reported) were occasionally investigated (Figure 3). A small number of studies focused on other polyesters (e.g. Tritan) (2 reported) or grouped under "Others"[9] (11 reported), while in 9 cases the material composition was not clearly specified.

[8] "Reported" refers to the number of times a given polymer type was reported across the dataset of 81 publications. Since a single study may investigate multiple FCMs and therefore multiple materials, the total number of reported cases exceeds the number of publications.

[9] Polyoxymethylene (POM), polymethyl methacrylate (PMMA), polyphenylsulfone (PPSU), melamine, silicone, metallocene-catalysed Polypropylene / general-purpose crystalline polypropylene.

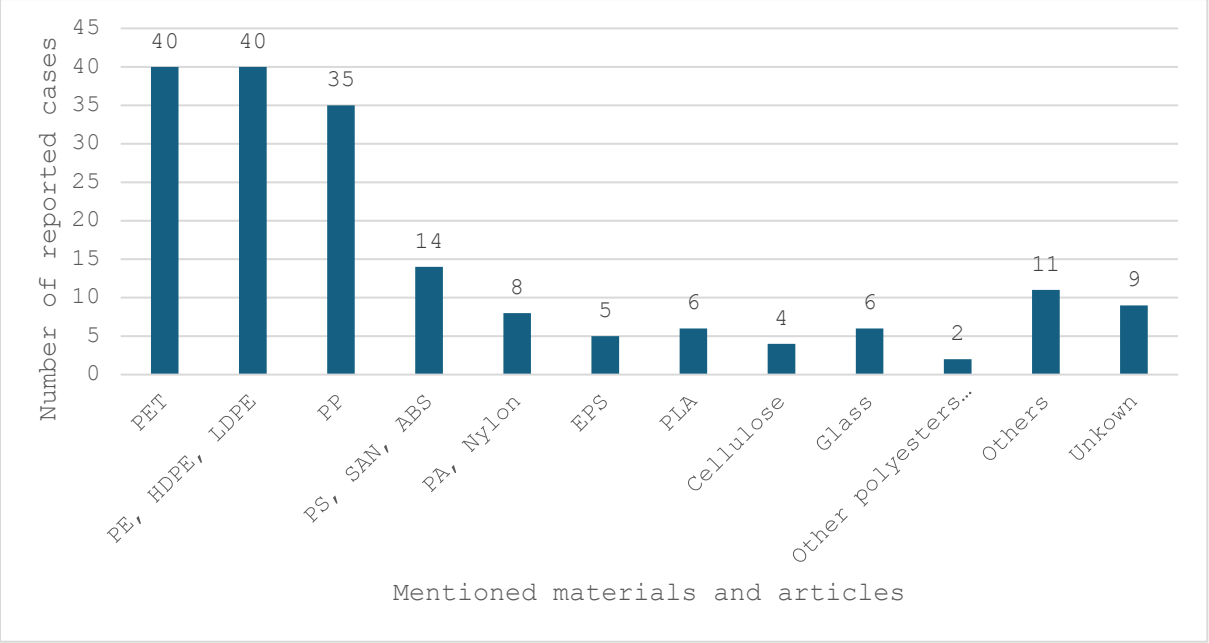

Figure 3: Frequency of mentioned materials and articles based on 101 FCM mentioned across 81 publications; a single publication may address multiple FCM type.

Two main experimental strategies were reported across the 81 reviewed publications for the 101 FCM samples. In most cases (71%) the FCM was empty or had been emptied, whereas in the remaining cases (29%), the actual contents of the FCM were analysed directly.

In the first strategy, when the FCM was empty or had been emptied (with or without pre-washing or rinsing steps), a simulant was introduced under various conditions. The vast majority of these tests (92% out of the 71%) used water-based simulants (ultrapure, distilled, deionized, or synthetic drinking water), either because the intended food contact was water (e.g. bottles) or for providing a medium for particle suspension (e.g. Akbulut et al., 2024; Caponigro et al., 2025; Duan et al., 2023; Hu et al., 2022; Li et al., 2022; Lin et al., 2024; Wang et al., 2023b). Non-water simulants were applied only occasionally (7% out of the 71%). These included regulatory food simulants (Regulation (EC) No 10/2011[3]) such as simulant A (ethanol 10%), simulant B (acetic acid 3%), and simulant D2 (ethanol 95% as a substitute for vegetable oil; Ubeda et al., 2019), as well as simulant D1 (ethanol 50%) (Guo et al., 2024). Ethanol was also used outside the regulatory context (Song et al., 2021) or in combination with other solvents in order to facilitate particle detachment (e.g. ethanol/acetone mixtures; Fang et al., 2024). Other less common test media included hexane (Guo et al., 2023) and HCl-adjusted water at different pH (Wang et al., 2023a).

In the second strategy, the actual contents of the FCM were analysed directly to detect the particles present in the packed food or beverage. In most cases, bottled waters were collected and filtered directly after purchase (e.g. Gambino et al., 2023; Hossain et al., 2023; Li et al., 2023; Hagelskjær et al., 2025), sometimes with repeated opening/closing of the caps (e.g. Braun et al., 2021; Singh, 2021; Winkler et al., 2019) or agitation (e.g. Nacaratte et al., 2023). Other studies used commercial beverages such as juice drinks, tea drinks, sodas, and energy drinks (Lam et al., 2024), or dry food matrices such as rice (Bai et al., 2022; Dessí et al., 2021). Bottled oils were also analysed directly, either after hexane-assisted dissolution and filtration or under accelerated storage conditions (Guo et al., 2023).

Regarding testing conditions applied to one or either of the two strategies, the broad patterns below emerged. The main test types covered by the publications reviewed are reported below. The tests description is not including every protocol detail; however, all studies in the dataset could be mapped, when time/temperature information was given, to one or more categories below based on their reported conditions.

i. Hot-fill conditions and/or heating: e.g. at 70–100°C for 5–30 min (cup/tea bag/plastic food container; e.g. Chen et al., 2023a; Duan et al., 2023; Kashfi et al., 2023; Kim et al., 2022; Li et al., 2025; Ranjan et al., 2021; Yang et al., 2023; Zhang et al., 2023); up to 121°C[10] for 20 min (bag; Wang et al., 2023b); 100°C for 60 min (plastic food container; Liu et al., 2022); 20-80°C for 24 h (bottle/screw cap; Zhou et al., 2024).

ii. Storage time at various temperature, notably covering all storage at refrigerated temperature and below, including hot-fill under certain conditions: 10 days at 20–40°C (plastic food container; Hussain et al., 2023); 10 days at 40°C (bottle/screw cap; Guo et al., 2023); 12 h at 4°C, 1-4 freeze-thaw cycles at -18°C for 8 h and at 25°C for 16 h (bottle/screw cap; Chen et al., 2023b); 1 to 14 days at 4°C followed by 1 h at 60°C (bag; Xuan et al., 2025).

iii. Other treatments of the FCM prior or during the testing: to mimic and possibly to inform on the stability of the polymer: repeated boiling cycles (kettles 100 repetitions; Shi et al., 2022), sterilisation (bottle/screw cap/bag, e.g. Gerhard et al., 2022; Zhao et al., 2025), microwaving or hot-plate heating (plastic food containers; e.g. He et al., 2021; Li et al., 2022; Pallavera et al., 2024), UV or sunlight treatment (bottle/screw cap/cup/film; e.g. Alvarez-Fernández et al., 2024; Lin et al., 2022; Ravanbakhsh et al., 2023; Wang et al., 2024), gamma irradiation at high doses (bottle/screw cap; Mikac et al., 2024) and oxidative treatments with H_2O_2 (bottle/screw, cap/tea bag; e.g. Taheri et al., 2023; Yousefi et al., 2024). Chemically modified aqueous simulants were sometimes used such as NaCl solution (grinding mills; Schymanski et al., 2020), HCl-adjusted pH (plastic food container; Wang et al., 2023a), CO_2/additives (bottle/screw cap; Chen et al., 2023b). Detergents were also used such as the surfactant sodium dodecylsulphate (Ossmann et al., 2018) and one not identified (Li et al., 2021).

With respect to representativity, two aspects could be distinguished: the choice of simulant and the applied test conditions.

Even though not exhaustive and possibly not representative of the market share, the tested article types and their related polymers provided a good picture of materials available to consumers, covering both single and repeated use articles. However, they did not cover materials and articles used in the food production chain.

29% of the 101 samples were tested directly on the packaged food. Among the 71% FCM samples tested with a simulant (bottles including infant feeding bottles (IFB), screw caps, cups, tea bags, kettles and brick cartons, plastic food containers, bags, films, mills, and bowls), 92% relied on water-based media mostly for technical reasons as water is a convenient medium for particle suspension and recovery. The use of water is considered to be acceptable in these studies, even though for chemical migration into water, the simulants specified in Regulation (EC) No 10/2011[3] for plastics would also include simulant C (ethanol 20%). Food simulants aim to 'extract' substances of related affinity (A, B, C for hydrophilic character; D1, D2 for lipophilic character, E for volatiles and semi-volatiles). In a polymer, organic substances usually move by diffusion toward the surface, driven by a concentration gradient. At the surface, a substance may pass into the food (or food simulant) according to its affinity since this dictates the partition coefficient between the FCM and the food/simulant,

[10] Regulation (EC) No 10/2011: "high-temperature/sterilisation band" (up to 121°C).

thereby establishing and maintaining the concentration gradient by mass transfer. Diffusion is not expected to be a mechanism to transport or generate MNP. Therefore, when assessing the potential to generate and/or release MNP, the representativity of food (simulants) against the regulated simulants is not critical. For instance, the use of liquid regulated simulants to test solid or semi-solid foods (e.g. liquid for trays) has less relevance than using either the real solid foods or other types of simulants for solid foods (e.g. quartz, etc.) if the formation/transport mechanism is abrasion/release rather than diffusion/partitioning.

Time/temperature conditions of testing used in the MNP studies have largely covered the conditions specified for hot-fill, heating and storage under various conditions as specified for compliance testing (Regulation (EC) No 10/2011[3]). Other treatments that are expected or foreseeable and may affect the MNP release, such as friction, opening/closure of caps, UV or sunlight were tested. Also, not foreseeable treatments such as gamma irradiation at very high doses (100 kGy) were tested. These studies remain useful to explore potential release mechanisms.

3.3 What analytical techniques are used to detect and quantify MP/NP released from FCM, and what are the reported key characteristics of these particles (e.g. size, shape, composition) (SQ2)?

Qualitative and quantitative analysis for and of MNP represent a complex emerging and challenging undertaking which entails a considerable potential for analytical pitfalls. In principle, both mass-based and particle number-based analytical techniques are available and applicable with varying method-dependent limits of detection in particle size dimensions. For a comprehensive analysis, i.e. full characterisation, the use of complementary combinations is needed for a reliable identification (size, shape and chemical composition, including polymer type, additives and other) and quantification per type of MNP. It is also essential to apply suitable sampling and sample preparation methods to obtain representative and reliable results. Methods will differ depending on the complexity of the samples and the analytical methods used (Ivleva, 2021).

3.3.1 Overview of the reported analytical techniques

A range of analytical techniques has been applied to the study of MNP; many FCM samples have been tested using two or more complementary techniques (90%, 161 out of 179 investigations[11]), while a smaller proportion employed a single technique (10%, 18 out of 179).

1. Vibrational spectroscopy dominated the analytical landscape, with Raman spectroscopy and micro-Raman (μ-Raman) spectroscopy, each employed in 33 cases (18%), followed by Fourier-transform infrared (FTIR) spectroscopy in 29 cases (16%) and laser direct infrared spectroscopy (LDIR) in 2 cases (1%). Other spectroscopic techniques included surface-enhanced Raman spectroscopy (SERS, 2 cases, 1%), near-infrared (NIR) spectroscopy (1, 0.6%), and optical photothermal infrared (O-PTIR) spectroscopy (1, 0.6%).
2. Electron Microscopy (EM) and imaging were widely reported, particularly scanning electron microscopy with energy-dispersive X-ray analysis (SEM-EDX, 27 applications, 15.0%). Fluorescence microscopy was applied in 8 applications (4%), and atomic force microscopy (AFM) in 4 studies (2%). Imaging tools less frequently used included field-emission SEM (FESEM, 1, 0.6%), NanoSEM 450 (1, 0.6%), transmission electron microscopy (TEM, 1, 0.6%), and digital holographic microscopy (DHM, 1, 0.6%).

[11] The total number of investigation (179) correspond to the total number of technics used mentioned among the 101 FCM sample tested across the 81 publications.

3. Fluorescence-based techniques combined with Nile Red (NR) staining to enhance the visibility of particles, were used in 13 studies (7%), and were often used in multiple techniques methodologies.
4. Thermal and mass spectrometry techniques were less commonly applied: pyrolysis–gas chromatography/mass spectrometry (pyr-GC/MS) and dynamic light scattering (DLS) each appeared in 3 studies (2%), while thermal desorption gas chromatography-mass spectrometry (TD-GC-MS) and size-exclusion chromatography coupled to high-resolution mass spectrometry (SEC-HR-MS) were used in 2 studies (1%) and 1 study (0.6%), respectively. Moreover, other mass spectrometry techniques involving non-targeted analysis strategies were also identified in 5 studies (3.0%)
5. Other specialised or emerging techniques included single-particle inductively coupled plasma mass spectrometry (SP-ICP-MS, 2, 1%) and single particle extinction and scattering (SPES, 2, 1%) techniques. It also included the hot needle test (2 applications, 1%), total organic carbon (TOC) analysis (1, 0.6%), and differential laser velocimetry (DLV, 1, 0.6%).

Overall, the findings indicated the predominance of vibrational spectroscopy and electron microscopy, complemented by a diverse array of emerging and supporting analytical techniques tailored to specific particle characteristics and research objectives.

3.3.2 Applied analytical techniques – strengths & weaknesses

Visual analysis by optical microscopy alone allows examination (sorting and counting) of microplastics and other particles of sizes down to the 20-50 µm range. This and other particle-morphology measuring techniques such as fluorescence microscopy with NR staining of particles are frequently used. However, for chemical characterisation and identification of the MNP polymer type spectroscopic techniques are required.

In most cases Raman but also Fourier-transform infrared (FTIR) spectroscopy techniques (1) were applied. Combination of these techniques with optical microscopy allows the detection, the chemical identification (depending on the availability of spectral databases) and morphological (size and shape) characterisation and the number-based quantification of MNP down to approximately 1 µm (Raman) and 10 µm (FTIR). Although being the preferred method, Raman analysis is challenging because MNP may contain or can be mixed with organic substances such as additives, oligomers, pigments or others. These may give Raman signals which interfere with polymer signals and can even be similar to them, giving rise to misidentification of particles. Consequently, the quality of measured Raman spectra may be compromised and decreased to levels where unambiguous identification is not possible. To overcome this major disadvantage of Raman analysis, it is essential to remove inorganic and organic non-plastic particles (e.g. precipitated slip agents) as well as inorganic and organic interferences (i.e. substances mixed with MNP or coated on them or adhering to them) before the measurement step. This was not done in most of the studies examined. This can be achieved by including cleaning steps such as rinsing/washing with solvents, acidic dissolution of mineral compounds or oxidative digestion of organic matrix components.

Electron microscopical methods (2) such as SEM or TEM can visualize particles – dependent on the magnification settings - down to the low nm range enabling characterisation of structural/morphological properties only. When SEM is coupled with EDX detection for elemental analysis, only limited access to chemical identity information is provided. EM imaging techniques were used in many cases as supporting analytical techniques in combination with the vibrational spectroscopic techniques described above.

The use of fluorescence microscopy imaging analysis after NR staining (3) was frequently reported. NR is a lipophilic stain/dye strongly fluorescent used to increase the visibility of

the treated particles. It is time- and cost-effective in providing results, in particular when combined with an automated particle counting tool using image analysis. However, the technique may significantly lead to misinterpretation concerning the nature of the detected particles. It also lacks specificity since any particles with an affinity for NR can be stained and visualised, so non-polar organic material in solid form may be misidentified/misclassified as 'plastic'. Also, due to its lipophilicity, NR may precipitate in aqueous media and generate fluorescence that mimics MNP. Another potential disadvantage, though less serious, is that the dye solvent (typically acetone) may swell the MNP polymers. Swelling effects, which are dependent on the type of polymer versus solvent used, can enhance or diminish the visibility. Partial (superficial) dissolution of smaller particles may occur 'melting up' into larger singular particles which may lead to undercounting of certain MNP polymers (Süssmann et al., 2024). Lastly, a less frequent problem is that the isolated particles may themselves contain fluorescence active substances such optical brighteners/whitening agents.

In a few publications, direct particle mass-based concentrations (4) were determined by application of conventional polymer-analysis methods such as (SEC) high-performance liquid chromatography (HPLC), high-resolution mass spectrometry (HRMS) and pyrolysis GC-MS (pyr-GC-MS), which offer strengths and limitations in analysing MNP. Sample preparation involves filtration; if a heat-resistant filter (e.g. sintered metal or ceramic) is used, it can be directly pyrolysed, while membrane filters require resuspension of retained particles before analysis. The sample can be pre-heated to remove volatile and semi-volatile compounds, then pyrolyzed at a higher temperature to break down any MNP on the filter. Specific polymers (e.g. PS, PE) can be easily distinguished based on their characteristic MS fragments. However, quantitation relies on calibration with authentic plastics, though size data are limited to filter-defined boundaries. Moreover, non-volatile oligomers may be misinterpreted as MNP.

Besides these techniques, also single particle-inductively coupled plasma mass spectrometry (SP-ICP-MS) (5) using the carbon-13 isotope was reported as a feasible methodology for size characterization, however it is restricted down to approximately 1 µm size detection due to the inherent limitations of carbon detection. This technique allows to provide number-based particle concentrations which can be recalculated into mass-based values assuming certain size, shape and material properties.

3.3.3 Reported key characteristics of the measured particles

Figure 44 and Figure 5 summarise the minimum and maximum sizes of the particles as reported in the publications[12]. The sizes were considered as reported and without any validated chemical confirmation that they are MNP. The particles include all reported shapes e.g. fragment, bead-like, fibre, film-like and other, as well as any colour. In most cases, it was not reported how the size was calculated; however, these Figures illustrate the size range of the measured particles only (not the counted numbers) indicating that these are mostly related to MP (>0.1 µm) rather than to NP (<0.1 µm).

[12] During data extraction, two variables were captured: minimum detected size and maximum detected size. The minimum size was not reported in 8 publications. The maximum size was not reported (no upper limit provided) in 17 of the 81 publications.

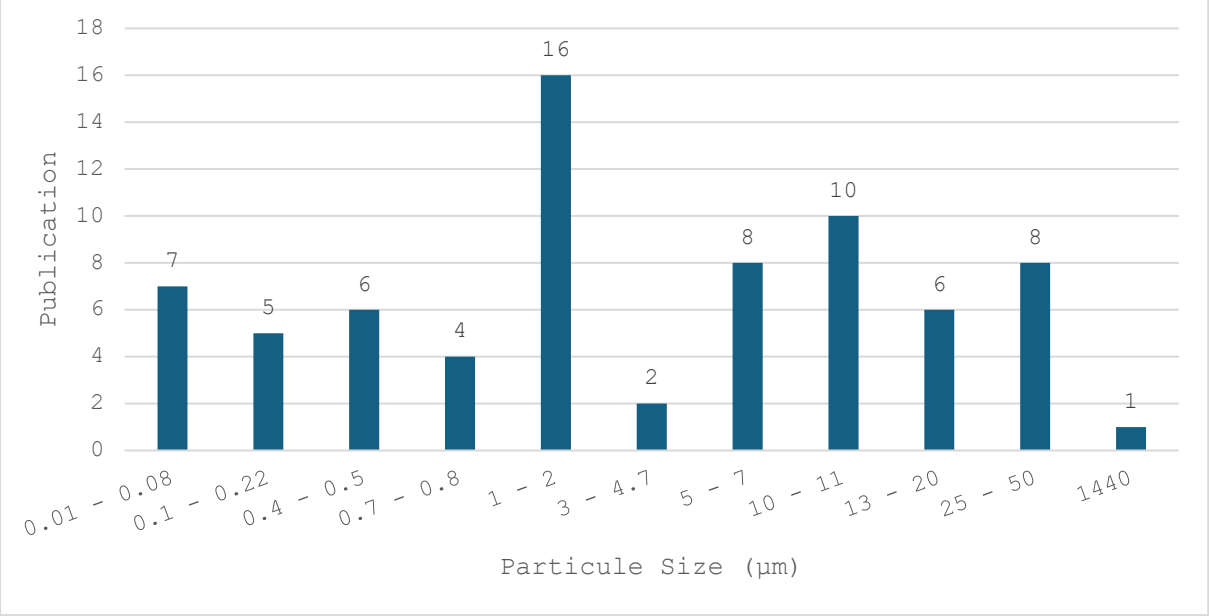

Figure 4: Minimum size reported based on 101 FCM mentioned across 81 publications.

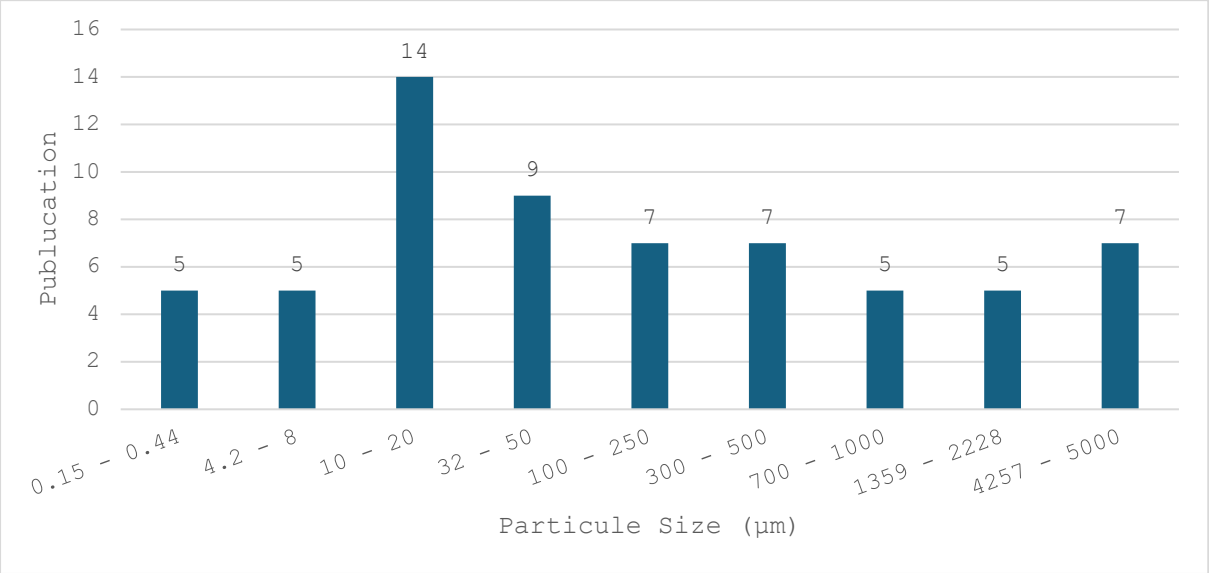

Figure 5: Maximum size reported based on 101 FCM mentioned across 81 publications.

Figure 4 and Figure 5 should not be compared as min and max sizes are not necessarily linked to each other. These values mirror the diversity of the methods used for sample preparation and measurement across the publications containing data related to the particle size. For instance, the highest bar (n = 16) in Figure 4 at 1-2 µm minimum size indicates the use of µ-Raman spectroscopy which is limited in resolution to this size range, although in a few cases, sizes down to 0.5 µm have been reported. Similarly, the next highest bar (n = 10) at 10 - 11 µm minimum size indicates the use and resolution limitation of FTIR spectroscopy. A further parameter triggering the prevalence of minimum and maximum sizes is the pore size of any filter used in isolating particles. So, when the pore size was relatively large, e.g. 20 µm, then the minimum size was limited to this value. Also, maximum sizes can be triggered by the pore size when the research interest was on small particles and therefore sample preparation included a first filtration to remove larger particles to focus on the particles remaining in the filtrate. Several studies reported particle sizes lower than 500 nm based on methods other than µ-Raman spectroscopy of single particles. Two of those studies (Banaei et al., 2024, Banaei et al., 2023) extracted tea bags

with hot water and isolated particle material by ultracentrifugation to obtain pellets which were then analysed. FTIR of the pellet material showed consistency with the parent FCM material and size measurements by TEM showed particles with the appearance of beads with diameters in the 100 – 190 nm range. Very high particle numbers were reported, in the range of 10^6 to 10^8 particles per tea bag. From the appearance of the particles and FTIR results, it cannot be excluded that the recorded particles were or contained precipitated oligomers or their agglomerates (see section 3.5). MS-based analysis (LC/MS) of the pellet material may have provided clarity on this point but it was not reported. Another study (Duan et al., 2023) reported particle numbers in the 10^{10} P/L range obtained from hot water treatment of PP FCM articles and then filtration at room temperature. Size measurements were done by nanoparticle tracking analysis and particles were reported in the 10 to 400 nm range. Identification of the particles by FTIR showed an additional C=O band which cannot be explained by PP MNP. It appears that migrated and precipitated slip additives (see section 3.5) such as fatty acids or amides could explain these findings, notably because similar results were obtained during 9 repetitions of this extraction test suggesting a continuous diffusion process of additive to the FCM surface. Another study (Wang et al., 2023b) on PP, PE, PET and PPSU FCM articles where the PP and PE articles were hot extracted and cold filtered, found sizes by SEM imaging in the 100 - 1000 nm range after fractionated filtration using 400, 200, 100 and 50 nm pore size filters only for the PP and PE articles but not for the PET (room temperature contact) and PPSU (50°C contact). Notably, all of these 4 studies have in common that hot water contact with FCM was followed by room temperature isolation of the particles. The presence of those particles could be attributed to the migration of additives or oligomers at high temperature followed by precipitation and formation of agglomerates at low temperature (see section 3.5).

Finally, besides these considerations and methodological triggers, the reported sizes represent the specific results of the particular samples reported in the literature considered, including the (non)applied precautions during sample preparation and hot or cold filtration or solvent rinsing of filtered particles (see section 3.5). This explains that not all reported sizes are necessarily corresponding to actual MNP.

Most studies measured and reported the particle concentrations in a number-basis (i.e. particles number per volume); however, a few studies measured the particle concentration directly mass-based or recalculated the number-based results into mass concentrations. In a study of Vega-Herrera et al. (2023), concentrations in 20 different brands of single use 0.5 L and 1.5 L plastic water bottles made from PET, PP and PE were measured after isolation using a 20 µm filter, dissolution of the particles on the filter in toluene and analysis by SEC-HPLC/HRMS. Over all the bottles (20 per polymer type and volume category), the particle concentration median value was 359 ng/L and the highest value was 4700 ng/L. These values refer to particles larger than 20 µm due to the filter pore size used. For comparison, in another study (Hagelskjær et al., 2025), particles larger than 1 µm were measured. On average, 97.5% and 93.5% of MP on a number-based measurement were < 20 µm and < 10 µm, respectively. The mass-based concentrations, recalculated from these particle numbers, ranged from 1 to 250 ng/L. The comparison of these data illustrates the low mass concentrations which are obtained for smaller MP (< 20 µm) compared to larger ones (> 20 µm) and indicates that concentrations of particles below 1 µm can be expected to be in the low ng/L and even pg/L range.

3.4 Are the particles released from FCM potentially from cross-contamination (e.g. air, sampling), food carry-over or manufacturing process and are they consistent with FCM composition (SQ3)?

The objective was to look for evidence of MNP release during the uses and foreseeable uses of FCMs. MNP may also be generated from FCM during their production and subsequent handling prior to filling with the food and any such prior-formed MNP would be conveyed by/present on the FCM before the contact. Both contact-generated and prior-formed/present MNP have been considered in this work since they will have the same essential polymer composition as the FCM. In contrast, any MNP originating from the environment of the FCM (e.g. 'dust' not related to the FCM identity) or from the food itself (e.g. environmental contamination during food production, FCM contamination[13] during food processing) are background contamination and have not been considered, even though they are of interest for the overall exposure of consumers (out of scope of this technical report). Thus, it is key to assess whether the composition of any MNP reported is consistent with the FCM, to establish the origin of the reported MNP and understand the possible mechanisms that drive their release.

Several characteristics of the particles can indicate their identity and origin, e.g. the polymer type, the colour and shape. The available information depends on the analytical methods used.

Overall, across the 81 publications, in about 44% of the studies the majority of the particles reported (ca. 60% or higher, being 60 or more P of the same polymer for every 100 particles counted) were judged by the authors to be definitely or likely associated with the FCM polymer type. In about 11% of the studies, the particles reported were not of the same polymer type as the FCM. In the remaining studies, the detection and identification methods used did not allow a conclusion. Inconsistencies may result from contamination, inadequate identification methods (e.g. NR staining without confirmation), or limited spectral resolution. Firm conclusions could only be drawn when sufficient chemical analysis was carried out to identify the MNP polymer types, which was not the case in numerous studies.

Even if polymer identification was not conducted or was not successful, the colour and shape of any particles detected can also be considered. In many cases, a wide variety of colours has been reported and unrelated to the colour of the FCM (e.g. Akbulut et al., 2024; Alak et al., 2021; Altunisik, 2023; Crosta et al., 2023; Hossain et al., 2023; Kankanige and Babel, 2020; Ravanbakhsh et al., 2023). Similarly, particles described as fibres have dominated in many reports (e.g. Altunisik, 2023; Caponigro et al., 2025; Crosta et al., 2023; Hossain et al., 2023) and these are generally not to be expected from thermoplastic monolayers. In contrast, fibres were very commonly reported in the studies of tea bags and coffee filters, which can be woven- or non-woven fibrous materials.

It must be stressed here; however, that, as the understanding of the strengths and weakness of the analytical methods used has developed over the period covered by the publications, in many cases the identifications made by the study authors can now be judged to be misidentifications due, for example, to incorrect identification of precipitated oligomers or additives as plastic NP or MP.

The incorrect or inconclusive studies mainly correspond to reports (i) on bottled water and other foods taken from the market for which the control samples (i.e. the water/food before packing) were not available, and (ii) where the particle identification techniques

[13] One should note that the understanding of the potential release during the uses and foreseeable uses contributes to the understanding of the possible cross-contamination by FCM during the food processing.

lacked power (e.g. NR staining used alone or microscopic analysis reporting only the particle shape in terms of plates, fragments, fibres, etc) or where the vibrational spectra (FTIR, Raman) were likely misidentified.

The most reliable studies with conclusive findings were the well-controlled studies that tested FCM of known provenance, under carefully controlled conditions, with appropriate procedural blanks, and using optimised and validated isolation, detection, counting and identification techniques.

It is noteworthy that only one study (Hagelskjær et al., 2025) carried out a full recovery test using a defined mixture of red coloured PE particles that were spiked into the sample and carried through the sample preparation/particle isolation procedure for correction of the counted MNP numbers. It is obvious that for such recovery tests, MNP standards of different sizes and polymer types are usually not available, which may have been the reason for the singularity of this recovery test.

Infant feeding bottles (IFB) were frequently studied but with varying reliability. An example of a well-controlled study was published by Gerhard et al. (2022): eight IFB made of PP and PA were tested using hot water extraction followed by temperature dependent filtration conditions (70°C versus room temperature) as well as supported by appropriate blanks across eight bottles. The reported number of plastic particles were drastically lower than the total particle numbers obtained under hot-contact extraction followed by room-temperature filtration protocol in a similar study on IFB (Li et al., 2020). For further details and explanations for this large discrepancy in reported particle numbers, see the case described below under section 3.5 (Gerhard et al. 2022).

The most conclusive studies concerning generation and release from FCM were typified by those papers reporting on the physical detachment of particles by abrasion of bottle caps, abrasion of the seals of 'Ziploc®' bags, and the rinsing-off of particles from tea bag tissue under the action of hot water and agitation. These studies are reported in more detail in section 3.6 on mechanisms.

3.5 Can certain substances (e.g. oligomers precipitate, fatty acids) mimic MP/NP, and how do they impact the interpretation of release data (SQ4)?

In general, the studies either analysed already prepacked mineral water or used water or aqueous food simulants as a medium for suspension of MNP. Any solid particle was then filtered through a membrane of low pore size and microscopically examined and possibly chemically analysed (see section 3.3). This approach inherently and unavoidably causes a 'by-catch' effect of non-plastics particles which depends on the applied membrane pore size, i.e. the overall particle number will increase with decreasing pore size. Besides the targeted MNP, i.e. expected to be congruent with the 'parent' FCM plastic(s), also 'other solids' such as environmental contaminants, solids from the FCM production and filling process as well as from the sample preparation procedure, will be retained on the filter membrane. These 'other solids' can include dust particles, textile fibres, paper particles, inorganics (e.g. mineral carbonates in mineral water), organic substances, pigments, non-FCM plastics, etc.

Substances of low solubility in water or aqueous food simulants may precipitate. This constitutes a significant potential to mimic the presence of MNP on the filter membrane and, hence, of false positives.

- Aforementioned organic substances include plastics additives migrated from the FCM, such as slip agents, fatty acids, antioxidants, organic pigments, oligomers and their

agglomerates. This was supported by the results of several studies. For instance, when FCM were tested with hot (initially boiling) water and the membrane filtration was done at room temperature instead of elevated temperature (e.g. 70°C) - this was the case in most studies -, then the particle numbers found on the filter membrane were by far higher compared to hot filtration (Gerhard et al., 2022). In this study eight PP or PA infant feeding bottles (IFB) were filled with hot water of 70°C. The authors compared the total particle numbers obtained after hot filtration (at 70°C) versus cold filtration, i.e. after letting the water cool down to room temperature. The effects found were in most cases extremely high with the highest particle number at 15 million P/L for cold filtration and up to 2,800 P/L with hot filtration. Another observation was the high number of PE-like particles characterised by µ-Raman spectroscopy in cold-filtered samples. For verification, particles from one bottle (IFB1) were analysed again with longer integration time which led to the disappearance of the PE-like particles, due to destruction by the laser. In contrast, the hot-filtered samples did not show any or only a few of these particles. It was concluded, based on TDS-GC/MS analysis of some of the PE like particles, that these particles may be the result of migration and precipitation of additives such as fatty acid esters, often used as slip agents in bottle production. The final MNP numbers identified by Raman after longer integration time was for this 'IFB1' bottle in the range of 2,800 P/L whereas all other IFB bottles were below the reported limit of 1,700 P/L, which was defined as the mean plus 3 times the standard deviation of 8 processing blanks. The range of the 8 processing blanks was 17 to 1210 P/L. No particles of the bottle materials (PP or PA) were found. The particles mainly consisted of polyethersulfone (PES; mean 84.2%) most likely released from cleaning wipes used in sample preparation and silicone (mean 12.8%) either due to silicone nipples or due to contamination as blanks also contained silicone MNP. For all bottles, at least 80% of all MP were in the size range between 1 µm and 10 µm.

- Another preceding study on IFB (Li and al., 2020) reported high particles numbers in the range of several millions per L which can be explained, on the basis of the (Gerhard et al., 2022) study, by the fact that the preceding study filtered at room temperature only. Similarly, when the solid particle material retained on the filter from the cold filtration of water that was before in hot contact with a polyolefin FCM was then rinsed with a solvent such as ethanol or methanol (Li et al., 2022; (a) Yang et al., 2024; Yang et al., 2023) which dissolves such mimicking particles but not MNP. Then (i) the particle number decreased drastically and (ii) in case of chemical identification by Raman spectroscopy the hit quality index (HQI) of the spectra from measured MNP increased significantly, i.e. much higher reliability of polymer identification was achieved. Li et al. (2022) analysed hot water extracts from PP bottles and other PO articles by µ-Raman spectroscopy and found particle counts of PE-like MP in the range of 26,000,000 per L. After rinsing with ethanol, the numbers of insoluble particles (assigned as MP) still remaining on the filter dropped down by 5 orders of magnitude to around 230 particles per L. By GC/MS analysis of the filtrate solution slip agent substances such as stearic acid and other were found. The authors emphasized that due to the very similar Raman spectra of precipitated fatty acid slip agents as micro additive particles (MAP) and PO, misassignments of MP are likely to have occurred in previous studies when such a solvent rinsing protocol was not conducted.
- Other cleaning steps of filtered particles were reported in cases where no hot water contact was applied. For instance, bottled mineral water was cleaned by acid treatment to dissolve mineral carbonates (Hagelskjær et al., 2025) or by complexation of minerals by the addition of ethylenediaminetetraacetic acid (EDTA) before filtering (Ossmann et al., 2018) thus reducing the number of retained particles and enabling better identification of MNP, e.g. by Raman. As mentioned under section 3.3, identification by Raman spectroscopy may be affected by interferences with mimicking substances (Süssmann et al., 2024). This decreases the identification HQI of the measured Raman spectrum or, even worse, when mimicking substances show similar Raman signals (which is possible for organic substances like slip agents or other), this may cause confusion with and misinterpretation of mimicking substances as MNP thus

leading to false positive findings of FCM polymers. In two publications the relevance of the HQI value on the reliability of the polymer identification is discussed. For instance, in the work of Li and al. (2022) the authors set the HQI at a minimum level of 70%. Conversely Gerhard et al. (2022) reported that even at >70%, PP, PE and fatty acids may not be differentiable anymore and that it is impossible to attain 100% reliability, especially with substances of similar chemical structure. Also, fluorescence could overlay characteristic peaks and cause misinterpretations of Raman signals. Therefore, in connection with Raman analysis, it is essential to report the applied HQI threshold level for acceptance of polymer identification.

- Another mimicking effect may result from the use of NR as a diagnostic fluorescent dye (see section 3.3). Chatterjee et al. (2023) reported that the formation of NR aggregates causes false positive counts in single NP counting when using automated particle counting on a custom-built fluorescence microscopy. This is due to the very low solubility of NR in water. A final concentration of 30 nM (9.5 µg/L) was found optimal but even then, the set-up detected 23 ± 3 NR aggregates/nL (i.e. 23 million per mL) in the blank, plastic-particle-free NR solutions, and so they have corrected all of their results for this blank background level.

These mimicking effects were reported or studied in the above-mentioned and a few other publications. This does not preclude the possibility that these effects were overcome in other publications, e.g. when filtration was done at proper elevated temperature (Yang et al., 2024), when filtered residues were rinsed with methanol or ethanol (Yang et al., 2024), and in case when the NR results were corrected. Overall, this phenomenon cannot be excluded, and the results can be brought to discussion/uncertainties for many publications. In any case, there is evidence that migrating additives could result in huge false positive errors (over-estimation) for MNP, which indicates the need for critical consideration when FCM have been subjected to heat treatment.

3.6 What mechanisms drive the release of MP/NP, and how do food type, material ageing, or interactions affect this release (SQ5)?

It is generally accepted that additives in nano-size form are too big to be released by diffusion processes from within a plastic FCM matrix, provided that the NP are properly incorporated into the plastic matrix (EFSA Panel on Food Contact Materials, Enzymes and Processing Aids (CEP) Panel, 2021, 2019, 2012). This being the case, this 'no migration' principle will also hold true for larger particles such as microplastics (MP). Plastic FCM are all thermoplastics or (much less commonly) thermosetting and, as such, the host polymer is a continuous matrix without discrete particles. At the microscopic level, plastics may have domains of crystalline and amorphous regions in the nanometric scale, but these are part of the polymer matrix and so the no-migration principle still pertains. Consequently, the release of MNP by diffusional processes from within a plastic FCM matrix that has a high dynamic viscosity is not expected.

The two main situations – in principle - that worth separate consideration are foamed plastics and woven- and non-woven filter materials. EPS and extruded polystyrene (XPS) are foamed plastics made by compression-moulding or extrusion-moulding polystyrene beads. The finished FCM may have granular and somewhat friable character (commonly with EPS, less so with XPS) including some unlinked expanded beads along with fragments of the beads. Woven and non-woven filter materials, most commonly encountered as tea bag tissue, have by design an open fibrous character.

There is a potential for release of MNP from an FCM through (i) mechanical stress or physical disintegration of the FCM surface and (ii) fibres shedding effects.

3.6.1 Mechanical stress or physical disintegration of the FCM surface

The most consistently reported mechanism of microplastic release is mechanical; by abrasion or friction during the use of FCM, such as the opening and closing of screw-cap bottles and of Ziploc® bags, the cutting of packaging, and the generation of MP from salt grinders.

Winkler et al. (2019) studied the effect of opening and closing PET bottles with HDPE screw caps on MP generation applying a series of opening/closings (1x, 10x, 100x) and analysing the caps and bottle necks by SEM imaging. Cap-bottleneck friction was found to increase MP on the HDPE screw caps significantly. For the three brands, 63,400; 1,225,500 and 333,800 HDPE particles on the inner cap surface were estimated, respectively, after 100 open/closes. The majority of particles were in the 1 - 5 µm range and most of the particles were on the grooved screw surface of the cap rather than on the sealing surface which constitutes the food (water) contact surface. MP occurrence in the bottled water itself was much lower at 148 ± 253 MP/L and was not significantly related to the applied mechanical treatments and also not to different bottle types (brand). In addition, PET bottles were mechanically stressed by squeezing/crushing treatments (partially emptied to allow significant deformation) and this had no influence on the particle numbers in the bottled waters.

In another study (Weisser et al., 2021), the impact of automated capping in a mineral water filling line was studied. It was found that the automated capping module ("capper") caused an increase of MP numbers of sizes > 11 µm in the water from uncapped (< LOD of 81 MP/L) to capped bottles (317 ± 257 MP/L) hinting at capping and bottle opening to be the main entry paths for MP in bottled mineral water.

It is noteworthy that for the two above examples, which are key for understanding the source and mechanism, there are somehow rather few MP compared to studies reporting thousands or millions of MP per L.

In the study of Ziploc® seals (Fang et al., 2024), three brands of self-seal (no slider) Ziploc® PE bags were opened and closed 10 times, using fingers to press the Ziploc® to close and then to pull open the seal. The released debris were collected using a variety of methods and analysed by SEM imaging and Raman. The authors estimated that approximately 5 (± 1 to 3) MP per millimetre along the Ziploc® length may be released during each closure/opening process. SEM images of the Ziploc® showed no scratches or deformation on the male or female rims when new but clear signs of deformation and fractures on the female rim and scratches on the male rim were seen after 10 times close/open. Released debris were already evident in the SEM images. The authors estimated that 49 particles correspond to ca. 0.9 mm^2 assuming that the particles were square.

In a study by Sobhani et al. (2020) the possible generation of MP by patting PS foam or during opening of plastic packages, i.e. by cutting, scissoring, tearing or when twisting of bottle caps was investigated using a quartz crystal microbalance (QCM) in combination with Raman and FTIR to chemically identify MP and SEM to visualize MP. The findings of this study are of semiquantitative character but indicate that any such packaging treatments are potential sources for MP generation. Besides being a potential source of MP release into packed foods, these data indicate also that any such or similar handling during sample preparation for analysis needs to be carefully thought over to avoid generation of artefacts.

Contrary to the Sobhani paper, more quantitative data were provided by 2 publications of Habib et al. (2022a, 2022b) which studied cutting boards (made from PE) used in butchers shops and supermarkets for preparation of meat and fish products, as sources of MP contamination. Detected particle numbers in meat products ranged between 1 and 7 P/g meat (in mass: 0.1 - 1.6 mg/g) with mean sizes in the range 500 to 2,500 µm. Similar results were found for fish products, too. The meat/fish samples were diced rather small (cut into small cubes) and so these results may have a 'worse-case' character and not be fully representative. On the other hand, there was clear evidence that cutting with knives damaged the surface of the PE cutting boards and led to particle release and a progressive loss in the weight of the board during its use.

In the study of salt grinders ('salt mills'), particle abrasion from five different salt mills with grinding burrs and/or grinding compartments made of plastic was investigated using µ-Raman spectroscopy (Schymanski et al., 2020). The plastics used in the construction of the mills included PS, POM and PMMA and they released particles identified as these plastics in the range of 2,400 to 76,280 particles per gram of milled salt. The average particle size was >10 µm. The unground salt had a background count of 4,230 P/g and these were reported to be mainly PET.

It is notable that, when doing abrasion tests to assess the release of nano-size additives used to manufacture plastic FCM and present in the final material or article, their release was not observed (EFSA CEP Panel, 2021, 2019). This may at first sight seem to be contradictory to reports that MP of the host matrix, the plastic itself, may be released by the action of abrasion. There is no contradiction though. The abrasion test involves shaking the FCM in contact with e.g. quartz sand and it intends to simulate contact between the FCM and solid foods (EFSA CEP Panel 2019, 2021). The forces involved are much weaker than the strong plastic-to-plastic frictional forces during bottle-capping/uncapping, opening/closing the narrow seals of Ziploc® bags, or the forces generated in salt mills to grind the salt or spice. Additionally, if any released MP did contain a plastic additive used in nano form, the additive would be expected to remain embedded in the plastic of the MP.

3.6.2 'Fibre shedding' effects

Many studies reporting high numbers of MNP release from tea bags now come into question as a result of increased understanding in the field. In testing the plausibility of the 'precipitated oligomers' alternative hypothesis, it is informative to consider 2 papers by Banaei et al. (2024, 2023) since they report on both a particle number basis and on the basis of the mass of solid material obtained by ultracentrifugation. In both studies, 300 empty tea bags were extracted using 600 mL water at 95°C with constant 750 rpm agitation. The tea bag tissue was squeezed out and removed using tweezers. The extract was left to cool down on constant stirring and then ultracentrifuged to spin down the released content into a pellet. The 3 types of tea bags gave between 3000 and 7000 µg of pellet (no exact values were found in the publication). NTA analysis of the pellet material resuspended at 100 µg/mL determined that the nylon tea bags gave 8×10^6 P/mL, the cellulosic tea bags gave 1.4×10^8, and the PP tea bags gave 1.2×10^9 P/mL. Considering an average pellet mass of 5000 µg coming from the extraction of 300 bags, these results would correspond to between ca. 1.3×10^6 and 2×10^8 particles released per tea bag. Similar results on particle numbers and pellet mass were reported for PLA tea bags (Banaei et al., 2023). If one tea bag gave 10 to 23 µg of 'pellet' this would correspond to 50 to 115 µg/L if the bag was used to make a 200 mL cup of tea. To put this into context, the overall migration limit for chemical migration from plastics (Regulation (EC) No 10/2011[3]) is 60 mg/L (more than 500-fold higher) and so precipitated oligomers and additives, etc. certainly could account for the particle material reported. The chance of precipitation

during cooling of the hot water extract is increased by the choice of using an exaggerated number of tea bags for the extraction and an exaggerated extraction time. The studies used 300 bags for a 600 mL water extract (for reasons of analytical sensitivity) which is about a 100-fold higher ratio than normal use which would rather be 1 tea bag for an approximately 200 mL cup (or larger) and the studies used an extraction time of typically 60 minutes whereas 2-4 minutes of immersion brewing would be more normal. This makes it highly likely that the extract is saturated in dissolved matter (including oligomers and additives) that will precipitate as the extract cools from 95°C down to room temperature.

On the other hand, other studies demonstrate more convincingly that MNP can be released from tea bag tissues. For instance, an article published by Busse et al. (2020) was provoked by a study by Hernandez et al. (2019). In that Hernandez study, tea bags of nylon or PET were brewed at 95°C and the extracts were concentrated to dryness by drop casting for EM analysis. The authors reported the release of MNP in the range of 10^9 particles in the sub-micron size range from one tea bag and 2.3×10^6 particles > 1 µm. As this sample preparation method unavoidably causes precipitation of any non-volatile substances such as oligomers, Busse et al. (2020) reacted on the Hernandez paper and published a comment together with the results of their own measurements on such tea bags. Differently to the work of Hernandez et al. (2019) where the isolated particles material as such was chemically analysed, the Busse paper applied µ-Raman spectroscopy that analyses the individual particles with sizes > 1 µm. The Busse paper reports much lower particle numbers per individual tea bag, more specifically in the range of 122×10^3 – 222×10^3 for the total of all particles > 1µm and for identified MNP in the range between 5.8×10^3 and 20.4×10^3. Busse et al. also applied LC/MS analysis for the presence of oligomers in the leachate and found significant amounts of a nylon dimer which supported one of their explanations for the high particle number reported in the Hernandez paper, i.e. that migrated and precipitated oligomers made up a large number of particles. The other explanation was that individual particles were not chemically analysed so that any particle either plastic or non-plastic was counted as MNP. Based on this Busse et al. study, the German Federal Institute for Risk Assessment (BfR) published a statement on the Hernandez paper and came to the conclusion that the high particle numbers presented by Hernandez et al. include for the greatest part oligomers and that the reported MNP numbers are by 2 or 3 orders of magnitude too high. Furthermore, BfR concluded based on their own EM images of tea bags that MNP are not generated by tea bags but are already present on the surface of the tea bags and are washed off by the hot water extraction (BfR, 2025)

Malynka et al. (2023) provides a detailed description of the materials used to make tea bags and their structure, using optical spectroscopy and FTIR. They describe that the primary structural elements of tea bags are fibres. On the surface of fibres are particles of microplastic debris which, in some cases, do not belong to the materials from which the tea bags are made, meaning some external contamination. The fibrous structure allows the bags to collect debris, including microplastics, due to electrostatic and mechanical trapping. These randomly distributed irregularly shaped particles and fibrils on- and in-the surface of the fibres, are usually smaller or comparable to the diameter of the fibres. After steeping of the bags in hot water, not all these microparticles on the fibres transfer, indicating a strong interaction between the fibre surface and microparticles.

Kim et al. (2022) investigated microplastic release from commercial tea bags. PE, nylon, PET, PA and PLA tea bags were placed into 40 mL glass vials (3 bags per vial) and heated under various temperatures for five minutes to one hour while shaken (70 rpm). The extract was filtered (1 µm) and the filter examined by optical microscopy. The filtered extract was also analysed for TOC and by SEM and EDS. SEM images of the extracted tea

bags themselves showed breakup of the surface after contact with the hot water. The SEM images of the filtered water extracts showed many shapes that are not fibres, and which hugely outnumbered the fibres. They are likely to be precipitated oligomers and other organics from the hot water extraction. The authors gave them little consideration and focused on the fibres that were released. Fibres were compared using EDS with the elements of tea bags to show a matching elemental composition. In 75°C water, after 30 min of extraction, the fibre release reached a plateau. Swelling of the polymer increased fibre release. When tea bags were damaged by cutting, there was a modest (about 2-fold) increase in particle release. The release of fibres was rather consistent for the different materials examined (PE, nylon, PA, PET, PLA) being in the range of 7 to 25. The authors estimated that with a single tea bag it is possible to ingest approximately 10 - 19 fibres per serving (> 1 µm in size).

Many studies report particles adhering to the surface of the FCM, possibly originating from the manufacturing process and being released during initial rinsing or washing. These particles are sometimes compositionally consistent with the FCM but, in other cases, they differ in colour, shape, or polymer type, suggesting external contamination. While such extraneous particles may not reflect the intrinsic properties of the FCM, they may remain relevant for assessing the overall/full consumer exposure.

There is currently no evidence for the significant de novo formation of particles and their subsequent release from the surface during the use of the FCM. The observed release mechanisms are dominated by mechanical processes such as abrasion, friction, with aging and material structure acting as potential amplifying factors. Aging such as embrittlement from UV/sunlight exposure may contribute indirectly by increasing surface fragility and friction-induced release. Additionally, some materials with open or fibrous structures, such as filter membranes, tea bags are prone to releasing/detaching fibres or fragments, especially under conditions of 'swelling' (e.g. contact with hot water) and agitation. In such cases, particle release may result both from manufacturing residues and mechanical breakdown of the fibre matrix, similar to shedding of microfibres by clothing textiles during laundry washing. Only a few studies have used fatty food simulants that could potentially interact with and swell non-polar plastics such as polyolefins; most studies have focused on water or (in a few cases only) water-ethanol mixtures, for reasons of ease of analysis.

3.7 Is there evidence of MP/NP release from mechanically recycled materials, and does recycling influence their release (SQ6)?

Only two papers explicitly tested FCM containing recycled plastic.

The study from Gambino et al. (2023) involved small sample sizes and lacked statistical power, but the analytical work was judged to be reliable. Bottled waters including 35 single-use PET bottles, 35 recycled PET (rPET) bottles (containing 30% to 50% rPET) and 60 returnable glass bottles, were purchased. The contents of the bottles were combined to make twenty 10-litre samples, being 7 samples from PET bottles, 7 from rPET bottles, and 6 from glass bottles. These samples were filtered (1.2 µm) and the filter was examined by µ-Raman spectroscopy. There was a low concentration of MP in all samples. On average, glass bottles showed the highest particle concentration with a mean of 8.7 ± 5.4 P/L followed by PET bottles with 5.1 ± 3.3 P/L. rPET bottles showed the lowest MP content with a mean of 3.3 ± 1.3 P/L. MP of 20 – 100 µm were dominant. Fragments were the most abundant particle shape (> 90%) and the rest were fibres. PET was the prevalent MP polymer in the water from PET bottles whereas polyethylene (PE) with additives were the most numerous in the water from rPET and glass bottles, suggesting a contribution from the cap. The samples were of different brands with (likely) different source waters preventing comparison and generalisation of the results.

The study from Mikac et al. (2024) investigated the degradation of virgin (vPET) and rPET by γ-irradiation in aqueous media. Granules of vPET and rPET along with cut pieces of a washed juice bottle purchased in a supermarket and labelled as 100% rPET, were held in water and irradiated at 10, 50 and 100 kGy. The aqueous extract was then analysed by DLS, by UV absorption spectroscopy and by Raman spectroscopy after 1 µm filtration. PET MP were reported to be found. There was no clear trend in results with respect to particle size range and numbers at the different doses for the different plastic samples. In contrast, the UV absorption of all the extracts increased with increased dose, indicating that chemical migration was occurring, possible increased by chemical reactions in solution brought about by the hydroxyl radicals and the solvated electrons that γ-irradiation of water produces. Additionally, and tellingly, MP further identified as Tinuvin (a hindered amine light stabilizer used as a plastic additive) from the Raman spectra, were also seen in the aqueous extracts. If correct, this finding suggests that a possible migration/precipitation mechanism operates. Therefore, the results reported as PET MP may be precipitated oligomers rather than MP, and confirmation would require further work.

Use-return-refill bottle loops are not 'recycling' loop but a mention in this section is appropriate. Some studies have investigated MNP release from articles reused through commercial return systems, such as refillable beverage bottles. The available evidence remains limited. These studies suggest that refillable bottles, from both PET and glass, may release higher levels of particles compared to single-use bottles (for example, MP and pigment particles coming from labels removed in the washing plant) but the data are not yet sufficient to draw firm conclusions (Ossmann et al., 2019; Schymanski et al., 2018).

4 Discussion

A total of 101 FCM samples were evaluated across 81 scientific publications investigating the potential presence and release of MP and NP.

There is a wide range and variety of plastic FCM used in the EU for different food types and, therefore, the list of tested FCM is never likely to be exhaustive. There was a preponderance of rigid articles tested (water bottles, cups, fast-food/take-away containers (Figure 2) and of tea bags, rather than flexible packaging materials. This seems to have been driven by considerations of ease of analysis in the early reports of high particle numbers coming from such uses. However, the range of polymer types tested (Figure 3) covered plastics suitable for both rigid and flexible FCM. Overall, the range of plastic FCM studied is judged to be reasonably comprehensive at this stage of research and understanding, with no major gaps identified.

The conditions used for testing have generally been sufficiently representative of actual or foreseeable conditions of use of the FCM studied. Additional factors, such as agitation, repeated-use, friction, mechanical wear and sunlight, have been explored, too.

The main discussion points are: water as test simulant, the use of complementary and reliable analytical methods, the substances mimicking particles and background sources, the release mechanisms (friction and abrasion as well as fibre shedding), the lack of identification and quantification of NP release, the pre-packed foods, the lack of good data on particle release expressed on a mass basis. The following examples are explored and discussed further to illustrate these important aspects.

Water was used in most cases as a simple matrix from which particles can be relatively easily isolated and characterised. This means that bottled mineral water was the most frequent food type taken from the market for testing and plain water was the most

frequently used simulant for testing plastic materials and articles. A few studies (Bai et al., 2022; Alak et al., 2021) have analysed more complex samples, including foodstuffs, using chemical digestion. As water was used in most cases, the question arises as to whether other food simulants (acidic, alcoholic, fatty, dry food) or real foods would cause the same qualitative and quantitative pattern of MNP release as water. Taking into account considerations of solubility, polarity, detergent action and solid frictional forces, water (alone) may not represent the worst case simulant to test the potential release of MNP.

Main release mechanisms seem to be (i) MP release due to frictional and abrasion forces between surfaces, such as bottle-to-cap, Ziploc® seals, grinder parts and cutting boards, and (ii) fibre shedding from tissue materials such as tea bags.

The formation and release of MP by frictional and abrasion forces is clearly illustrated in the many studies on bottles and screw closures. In studies of bottle caps, Winkler et al. (2019) found that 100 repeated opening and closing of PET bottles with HDPE screw caps generated 63,400 to 1,225,500 HDPE particles on the inner cap surfaces, depending on the bottle brand. The majority of particles were in the 1 to 5 µm range. Most of them were on the grooved screw surface of the cap, rather than on the sealing (food contact) surface. MP occurrence in the bottled water itself (with a single opening) was much lower, at 148 ± 253 MP/L, and was not significantly related to the bottle brand. The mechanical stressing of PET bottles by squeezing/crushing treatment had no influence on the particle numbers in the bottled waters, indicating that PET is tough enough and elastic enough to withstand such treatment. It seems that even if particles are generated by abrasion during closing/opening, the majority either fall outside of the bottle or are retained at the cap-neck interface and do not transfer to the water. Weisser et al. (2021) studied the automated capping in a mineral water filling line and concluded that the capper caused an increase of MP numbers in the water from uncapped to capped bottles, pointing at capping and bottle opening to be a source of MP in bottled mineral water. Besides these studies, two publications (Habib et al., 2022a, 2022b) explored mechanical stress when slicing foods on PE cutting boards under conditions as applied in butchers' shops. The reported results indicate that, due to the applied strong cutting forces, such cutting boards can be damaged by knives with the generation of plastic particles and their subsequent release onto the cut meat and fish pieces. The extent of release is expected to be a function of the polymer composition and the age of the cutting board, and may vary with the working conditions (cleaning frequency, handling of the cutting knife, any use of cleavers, etc).

There is clear evidence of microfibre shedding from tea bags and similar woven- and non-woven materials. However, the early reports suggesting that millions or even billions of MNP per plastic tea bag were released into hot water have been re-evaluated in the light of improved understanding in the field. The studies used hot water extraction followed by room temperature isolation of particles along with incomplete or inconclusive polymer identification. The very high particle counts can largely be attributed to migration of additives or oligomers and precipitation/formation of agglomerates at lower temperature. More reliable estimates are in the range of 122,300 to 222,800 total particles > 1 µm and 5,800 to 20,400 for identified MP per tea bag (Busse et al., 2020) after infusion of nylon tea bags in boiling water for 5 minutes. In another study (Kim et al., 2022), for bags made of PE, nylon, PET or PLA, the numbers from one tea bag were estimated in the range of only 10-19 MP fibres > 1 µm per serving of tea. EM images have indicated that MNP are likely not generated by the extraction process, but are already present on/in the surface of the tea bag tissue and are washed off by the hot water (BfR, 2025; Malynka et al., 2023; Busse et al., 2020).

The particles reported in the publications mostly relate to MP (> 0.1 µm), rather than NP (< 0.1 µm). The lack of suitable sample preparation and chemical identification methods

for NP release is a common limitation in many studies and it can be illustrated by one study on teabags. If properly used, Raman or FTIR spectroscopy are strong techniques for the identification of polymer types. However, they are not suitable for sizes smaller than approximately 1 µm. The usual method for NP observation and structural identification is electron microscopy, but sample preparation for these techniques may give rise to artefacts. In the Hernandez et al. (2019) study, hot water extracts of nylon or PET tea bags were drop-cast and taken to dryness for EM analysis. This inevitably causes precipitation of non-volatile substances that may have migrated into the hot water, such as additive and oligomers, which may then be misidentified as NP. Even if EM is coupled with EDX, only limited chemical information becomes available (e.g. C, H, O) which does not allow full chemical identification. Lack of techniques and their combinations to study a potential NP release is a clear gap.

Studies of pre-packed foods were almost entirely limited to bottled water and these illustrate that few if any studies have followed the whole food chain to determine at which point MNP may be entering. The water from 20 different brands of single-use water bottles made of PET, PP and PE was filtered (20 µm) and the particles on the filter were dissolved in toluene and analysed by SEC-HPLC/HRMS (Vega-Herrera et al., 2023). Over all bottles, the median concentration of all particles was 359 ng/L with a maximum of 4,700 ng/L. It should be noted that a rather large pore sized filter was used (20 µm), so any smaller MP would not be included. Hagelskjaer et al. (2025) used a smaller, 1 µm filter and on a number-basis, on average 97.5% of MP were < 20 µm and 93.5% were < 10 µm. In the bottled waters, the mass-based concentrations calculated from particle numbers and so subject to uncertainty about the exact shape, ranged between 1 and 250 ng/L.

In only few publications was the mass of MP determined directly or estimated from the particle numbers and size distributions. In none of the publications was the size of the particles measured and reported in 3-dimensions (x,y,z). Due to the particle analysis using typically microscopy, information on at least 2 dimensions would in principle have been available, but this was not reported. In most publications, it was not clear how the size ranges were calculated. The terms used to describe the shapes was consistent with descriptors such as fragmented, fibrous, film-like, irregular or spherical being used. The calculated size-to-mass ratio depends on particle shape and how the size is reported. On the one hand, assuming that the size is representative of all 3 dimensions, a particle of, e.g., 10 µm size has 1000 times the mass of a 1 µm particle. If surface area rather than mass would be a more relevant metric, the 10 µm particle would have about 100 times the surface area of the 1 µm particle. On the other hand, if the particle is a fibre and its length is the size reported and the fibres have the same cross-section, a 10 µm fibre has 10-times the mass and 10 times the surface area of a 1 µm fibre.

The need to avoid or at least report background sources (by appropriate procedural blanks) and artefactual particle formation (such as from mimicking substances), is well illustrated by the study of infant feeding bottles by Gerhard et al. (2022). Eight PP or PA bottles were closed with a silicone teat and extracted with hot water at 70°C for 1 min with shaking, immediately followed by filtration (0.8 µm) still at 70°C. The total MP count was up to 2,800 particles/L. No particles of the bottle materials (PP or PA) were found. The particles mainly consisted of polyethersulfone originating from background contamination and some silicone. Drastically higher particle numbers (up to 15 x 10^6 P/L) were found for all bottles when cold filtration was used, indicating that additives or oligomers precipitated.

Table 2 contextualizes the results for the reliable and conclusive studies discussed above along with two further examples of abrasion release (Ziploc® bags and salt mills) that are described in section 3.6.1. The values are not directly comparable due to different filters, detection limits and count-to-mass conversions used.

Table 2: Reported MP levels and test conditions across conclusive studies; P, particles

Reference	Particles number / mass in food or water	Size (if mentioned)	Contact type / key conditions
Vega-Herrera et al. (2023)	Mass-based (after dissolution): median 359 ng/L, max 4,700 ng/L	> 20 µm	20 bottled water brands in PET, PP, PE
Hagelskjær et al. (2025)	Recalculated mass from number: ≈ 1–250 ng/L	Measured > 1 µm; 97.5% are < 20 µm; 93.5% are < 10 µm	10 bottled-water brands; number-based counts converted to mass.
Gerhard et al. (2022)	After µ-Raman: one bottle ≈ 2,800 P/L; 7 others < LOD (1,700 P/L). Blanks: 17–1,210 P/L	≥ 80% between 1 and 10 µm	Infant feeding bottles (PP/PA); Identified particles mainly PES (~84%) and silicone (~13%); no PP/PA detected.
Li et al. (2022)	230 P/L	n/r	PP bottles / polyolefins
Winkler et al. (2019)	Bottled water: 148 ± 253 P/L. Cap surface debris: 63,400; 1,225,500; 333,800 P/cap.	Mostly 1-5 µm	PET bottles with HDPE screw cap; for the cap, 100 open/close cycles.
Weisser et al. (2021)	317 ± 257 MP/L (capped) vs < LOD (81 MP/L) (uncapped).	n/r	Automated capping module in a mineral water filling line.
Fang et al. (2024)	≈ 5 (± 1–3) P per mm of zip length per open/close cycle.	n/r	PE Ziploc® bags (no slider); 10 cycles
Schymanski et al. (2020)	2,400–76,280 P/g milled salt; background unground salt ≈ 4,230 P/g.	Average > 10 µm	Plastic salt mills (PS, POM, PMMA)
Busse et al. (2020)	Per tea bag: 122,300–222,800 total P of which 5,800–20,400 identified as MP	> 1 µm	Tea bag brewing
Kim et al. (2022)	≈ 10–19 fibres per serving (> 1 µm).	> 1 µm	Tea bags
Habib et al. (2022a, 2022b)	1-7 P/g in meat cutting (in mass: 0.1-1.6 mg/g)	Mean values 500-2,500 µm	Cutting boards

5 Conclusion

The objective of this literature review was to look for evidence of micro- and nanoplastics (MNP) release during the uses of FCM, i.e. transferred to the food after generation during contact between the FCM and the food or generated during the FCM production and subsequent handling, prior to filling with the food.

Despite the large number of publications investigating the release of MNP from FCM, the available evidence remains limited concerning the characteristics and quantities of released MNP from FCMs. Most of these publications use water or aqueous food simulants as FCM contact medium for suspension of released MNP. Foods other than mineral water are tested only in few cases.

Many publications are affected by methodological shortcomings and uncertainties. Reported findings are strongly influenced by weaknesses in test conditions, pitfalls in sample preparation and deficiencies in the reliability of analytical data with the difficulty of distinguishing release of MNP originating from FCM from other particle sources. These other sources include background contamination (during analysis, from the environment of the FCM or from the food itself) or substances that mimic MNP, such as lipophilic chemicals with low solubility in water (migrating during testing at elevated temperatures) and precipitating during cooling.

The most robust data suggest that the release of MP is mainly caused by mechanical processes, such as abrasion, friction of FCMs (e.g. opening/closure of caps and of storage sealing bags, capping, mill grinding), with aging and material structure acting as potential amplifying factors such as embrittlement from UV/sunlight exposure. Additionally, some materials with open or fibrous structures (e.g. woven or non-woven synthetic and natural fibres, such as tea bags) are prone to releasing/detaching fibres or fragments, especially under conditions of temperature-induced 'softening/swelling' of fibrous networks and mechanical stress such as agitation. There is no evidence supporting diffusion-driven release mechanisms, as expected due to the constraint of the size itself. There is currently no evidence for significant de novo formation of particles and their subsequent release from the surface during the use of the FCM.

There are gaps in the published literature, including the lack of validation of the methodologies used, a paucity of information (and suitable analytical methods) on the release of NP, and a lack of studies on the contact of FCM with foodstuffs. Most available results concern microplastics whereas data on nanoplastics are almost entirely lacking. In view of the findings (mechanisms, contaminations, mimicking substances, particles numbers and masses generated during the use of FCM), it is concluded that (i) there is evidence of microplastics released during the uses of FCM, (ii) this release is due to mechanical stress, such as abrasion and friction, or due to materials with open or fibrous structures, (iii) despite the uncertainties described above, the extent of the actual particle release is much lower than the results presented in many of the reviewed publications.

In view of all this, there is no sufficient basis at this stage to estimate MNP exposure from FCM during their uses. This review provides recommendations on identified gaps and related future research needs (see the section 6 below).

6 Recommendations

It is recommended to fill the identified gaps on:

1. the lack of validated test protocols including polymer MNP standards and recovery tests using those standards;
2. the paucity of information (and suitable analytical methods and their combination) on the release of nanoparticles (< 0.1 µm) and microparticles < 1 µm;
3. the identification of the composition of any purported MNP, their size and their quantity (number-based and mass-based);
4. the contact between non-polar FCM plastics and non-polar fatty food/simulants;
5. the testing of real foods (other than water), considering possible mimicking substances;

6. the need to estimate dietary exposure to MNP from FCM and place into perspective with other exposure sources.

It is recommended to revisit these findings and outcomes as necessary and to repeat this review in about 5 years. This timeframe aims allowing sufficient time to provide new data such as the development and use of validated methods and reference materials. Taking into account that most of the usable data recorded in this literature search are from the more recent years, a review in 5 years' time seems to be appropriate because by then one can be reasonably confident to find enough new information to make the (re-)review worthwhile. The FCM WG will be keeping a watching brief on progress in this area and that will inform if 5 years is too long or too short.

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8 Abbreviations

ABS	acrylonitrile–butadiene–styrene
AFM	atomic force microscopy
BPA	bisphenol A
DHM	digital holographic microscopy
DLS	dynamic light scattering
DLV	differential laser velocimetry
EDS	energy-dispersive spectroscopy
EDTA	ethylenediaminetetraacetic acid
EDX	energy-dispersive X-ray analysis
EM	electron microscopy
EPS	expanded polystyrene
FCM	food contact materials
FESEM	field-emission scanning electron microscopy
FTIR	fourier-transform infrared spectroscopy
GC-MS	gas chromatography-mass spectrometry
HACCP	hazard analysis and critical control points
HDPE	high-density polyethylene
HPLC	high-performance liquid chromatography
HQI	hit quality index (spectral matching metric)
HRMS	high-resolution mass spectrometry
ICP-MS	inductively coupled plasma mass spectrometry
IFB	infant feeding bottle(s)
LDPE	low-density polyethylene
LDIR	laser direct infrared spectroscopy
LOD	limit of detection
MAP	micro additive particle (e.g. precipitated fatty-acid slip agents)
MNP	micro- and nanoplastic
MP	microplastic
MS	mass spectrometry
NIR	near-infrared spectroscopy
NP	nanoplastic
NR	nile red (fluorescent dye)
NTA	nanoparticle tracking analysis
O-PTIR	optical photothermal infrared spectroscopy
PA	polyamide (nylon)
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyls
PE	polyethylene
PES	polyethersulfone
PET	polyethylene terephthalate
PLA	polylactic acid
PMMA	polymethyl methacrylate
PO	polyolefin
POM	polyoxymethylene

PP	polypropylene
PPSU	polyphenylsulfone
PS	polystyrene
PVC	polyvinyl chloride
P	particles
QCM	quartz crystal microbalance
rPET	recycled PET
SAN	styrene–acrylonitrile copolymer
SEM-EDX	scanning electron microscopy with energy-dispersive X-ray analysis
SERS	surface-enhanced Raman spectroscopy
SP-ICP-MS	single particle inductively coupled plasma mass spectrometry
SPES	single particle extinction and scattering
SQ	sub-question
SRS	stimulated Raman scattering
TD-GC-MS	thermal desorption gas chromatography-mass spectrometry
TEM	transmission electron microscopy
TOC	total organic carbon
TTC	threshold of toxicological concern
vPET	virgin PET
XPS	extruded polystyrene

Appendix A – Background activity from the EFSA FCM Working Group and the EFSA FCM Network

As a starting point for this work, past activities of the EFSA FCM WG and the EFSA Member State FCM Network on the potential release of MP and NP from FCM during their use were reviewed[14].

The FCM WG reviewed in particular two publications by Qian et al. (2024) and Milne et al. (2024), which reported the detection of MP and NP in food matrices such as bottled water and processed protein-rich food. The WG highlighted several limitations in these studies. Qian et al. detected particles > 60 nm in bottled water using stimulated Raman scattering (SRS) microscopy, estimating approximately 500,000 particles per litre (~0.01 µg/L). However, the study design did not clearly demonstrate whether the particles originated from the packaging or from other sources and whether all of these particles were microplastics at all, as only 10% of the particles had spectral matches covered by their Raman spectra polymer library. Milne et al. reported high concentrations of microplastics (> 45 µm) in processed foods. The WG underlined that neither study provided conclusive evidence linking the detected particles to the material and articles in which the water or food was packed. Instead, alternative sources such as dust or background contamination during handling and preparation could explain the observed findings. Importantly, the mass-based concentration of particles reported by Qian et al. (ca. 0.01 µg/L) was about one order of magnitude lower than the threshold of toxicological concern (TTC) for DNA-reactive mutagens which is 0.15 µg/kg food[15]. Although this TTC does not apply to nanomaterials, the comparison was used illustratively to contextualise the level of possible concern. Moreover, the WG noted that certain chemical contaminants, such as bisphenol A (BPA), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs), had been associated with PET particles in the study. However, the estimated concentrations of these substances (<< 10 ng/L) were considered too low to represent a significant health risk under current exposure conditions.

In the FCM Network meetings, several Member States, Norway, Sweden, and Germany, shared findings from national investigations. While most of these focused on the occurrence of MP in food and drinking water, a few studies were particularly relevant to the release of MNP from FCM during consumer use. In particular, the study by Hernandez et al. (2019) on the release of billions of MNP per plastic tea bag in hot water (95°C). This study was also discussed at the FCM WG, who questioned the reproducibility and interpretation of the results. A consortium of researchers from several German institutions including the BfR also questioned the experimental approach, and the results presented in the original study (see section 3.6), the origin of particles, whether from packaging or other sources, remained uncertain. This was a recurring concern. Nonetheless, the presence of such particles throughout the production and packaging chain justified further investigation into release mechanisms, including abrasion or degradation under typical use conditions. An additional methodological challenge related to the reliability of particle identification. Analytical interferences were highlighted by Gerhard et al. (2022), who showed that fatty acids and esters released from infant bottles can precipitate upon cooling and mimic the spectral signatures of MP, leading to possible false positive results. This issue further complicated the interpretation of existing data and underlined the need for improved and

[14] FCM WG in March 2024 (45th meeting) and FIP FCM Network (7th meeting in 2019 and 8th in 2022).

[15] The EFSA Scientific Committee (2012) concluded that a threshold of 0.15 µg/person per day would provide sufficient protection against (genotoxic) carcinogenic and heritable effects when it can be ruled out that the compounds are part of the exclusion category. This threshold of 0.15 µg/person/day, for a person of 60 kg body weight, corresponds to 0.0025 µg/kg bw per day. Considering that a person consumes 1 kg of packed food, it corresponds to 0.15 µg/kg food.

standardised analytical methods. These limitations, consistently called for methodological refinement and harmonisation.

Overall, these discussions underscored substantial knowledge gaps concerning the actual release of MNP from plastic FCM during use. While environmental contamination remains the dominant and more established source of particles found in food and beverages, the specific contribution from FCM is still poorly characterised.

Appendix B –Structured literature review

B.1. Eligibility criteria

Table A. Eligibility criteria

Criterion	Inclusion	Exclusion
Study focus	Studies focusing on FCM, whether virgin or recycled, with or without packaged food or food simulants; providing experimental data on the release or detection of MP/NP; conducted under relevant testing conditions such as temperature, duration, mechanical stress, food type (acidic, fatty, aqueous), or material ageing; employing analytical techniques to detect and characterise MP/NP (e.g. size, shape, composition), including assessment of potential contamination sources; and/or investigating substances (e.g. oligomers, fatty acids) that may mimic MP/NP and result in false positives.	Studies not involving FCM, lacking data on MP/NP, or focusing solely on environmental aspects.
Time frame	Published between **1st January 2015 and 20 January 2025**, with the cut-off date corresponding to the finalisation of the literature search	Published **before 2015**
Language	English	Other languages
Publication type	• Primary research articles • Review articles (only conclusions supported by primary data were considered)[16] • Book chapters • Conference proceedings • Older studies referenced in reviews (for background purposes if relevant)	Letters to the editor Expert opinions Editorials Thesis

B.2. Literature identification

A structured literature search was conducted to identify studies addressing the release of MP/NP from FCM under relevant use or simulated use conditions. The strategy was developed to ensure comprehensive coverage of peer-reviewed scientific literature.

Input from members of the EFSA FCM WG was also considered to identify any additional relevant publications not captured through the database search.

[16] Review articles were initially included, so identified in the search and collated but excluded from the final data extraction; only primary research studies were extracted.

B.2.1.Sources of evidence and search strategy

The following table B present the databases used for the search:

Table B. databases used for the literature review

Database	Platform
Scopus	Scopus.com (Elsevier)
Web of Science Core Collection: • Science Citation Index Expanded • Conference Proceedings Citation Index • Book Citation Index • Emerging Sources Citation Index	Clarivate

The databases were chosen to provide broad coverage of peer-reviewed scientific literature. They have a multidisciplinary focus that includes topics such as environmental science, material science, and toxicology.

B.2.2.Search strategies

Search terms were identified through a combination of expert input, thesauri and analysing a set of expert-suggested papers. Boolean operators were used to combine terms, applied to the title, abstract, and keyword fields. The search syntax was adapted to the features of each platform. Time and language publication limits were applied as determined by the eligibility criteria.

A first search was run on 20th January 2025 addressing the release of MP and NP and FCM (Table C and Table D. Search strings on microplastics/nanoplastics: Web of Science platform). An additional search on oligomer precipitation and FCM was performed on 2nd February 2025 (Table E and Table F).

Table C. Search strings on microplastics/nanoplastics: Scopus

Set	Query	Results	Concept
#1	TITLE-ABS-KEY (cutlery OR cup OR cups OR fcm OR FCMs OR "Food Contact Material*" OR fork OR forks OR knife OR knives OR plate OR plates OR spoon OR spoons OR tray OR trays OR ((bag OR bottle* OR cap OR caps OR container* OR film OR glass OR glasses OR package OR packages OR packed OR packaging) NEAR/5 (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR formula OR fruit* OR meat OR milk OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR "soft drink*" OR softdrink* OR vegetable* OR water OR wine)) OR (beverage* W/3 can) OR (beverage* W/3 cans) OR (beer W/3 can) OR (beer W/3 cans) OR (drink W/3 can) OR (drink NEAR/3 cans) OR (beers W/3 can) OR (beers W/3 cans) OR (drinks W/3 can) OR (drinks W/3 cans) OR teabag OR teabags OR "tea bag*") OR TITLE-ABS-KEY(((bag OR bottle* OR cap OR caps OR container* OR film OR glass OR glasses OR package OR packages OR packed OR packaging) W/5 (plastic OR plastics)) AND (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods*	1,258,514	FCM

	OR formula OR fruit* OR meat OR milk OR recycl* OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR "soft drink*" OR softdrink* OR vegetable* OR "water simulant*" OR wine))		
#2	TITLE(CUTLERY OR CUP OR CUPS OR FCM OR FCM OR "FOOD CONTACT MATERIAL*" OR FORK OR FORKS OR KNIFE OR KNIVES OR PLATE OR PLATES OR SPOON OR SPOONS OR ((BAG OR BOTTLE* OR CAP OR CAPS OR CONTAINER* OR FILM OR GLASS OR GLASSES OR PACKAGE OR PACKAGES OR PACKED OR PACKAGING) AND (BEER OR BEERS OR BEVERAGE* OR DAIRY OR DRINK* OR FISH OR FISHES OR FOOD OR FOODS* OR FORMULA OR FRUIT* OR MEAT OR MILK OR "TAKE AWAY" OR "TAKE OUT" OR TAKEAWAY OR TAKEOUT OR "TO GO" OR SOFTDRINK* OR VEGETABLE* OR WATER OR WINE)) OR ((BEVERAGE* OR BEER OR BEERS OR DRINK OR DRINKS) AND (CAN OR CANS)) OR TEABAG OR TEABAGS OR "TEA BAG*") OR TITLE(((BAG OR BOTTLE* OR CAP OR CAPS OR CONTAINER* OR FILM OR GLASS OR GLASSES OR PACKAGE OR PACKAGES PACKED OR PACKAGING) AND (RECYCL* OR PLASTIC OR PLASTICS)) AND (BEER OR BEERS OR BEVERAGE* OR DAIRY OR DRINK* OR FISH OR FISHES OR FOOD OR FOODS* OR FORMULA OR FRUIT* OR MEAT OR MILK OR "TAKE AWAY" OR "TAKE OUT" OR TAKEAWAY OR TAKEOUT OR "TO GO" OR "SOFT DRINK*" OR SOFTDRINK* OR VEGETABLE* OR "WATER SIMULANT*" OR WINE))	289,709	
#3	#1 OR #2	1,255,390	
#4	TITLE-ABS-KEY ("Micro plastic*" OR microplastic* OR "Nano plastic*" OR nanoplastic* OR (plastic* W/3 fragment*) OR (plastic* W/3 particle*) OR (polymer* W/3 fragment*) OR (polymer* W/3 particle*) OR (synthetic W/3 particle*)) OR TITLE ((plastic* OR polymer*) AND (fragment* OR particle*))	95,785	Microplastics
#5	TITLE-ABS-KEY (abrasion OR aging OR ((analys* OR analyt* OR analyz*) W/3 method*) OR ((analys* OR analyt* OR analyz*) W/3 test*) OR ((analys* OR analyt* OR analyz*) W/3 technique*) OR detect* OR determin* OR (interact* W/3 beverage*) OR isolat* OR quantif* OR quantit* OR releas*)	25,378,447	Release
#6	#3 AND #4 AND #5	1,475	FCM AND Release AND Microplastics
#7	TITLE-ABS-KEY((interact* W/3 beverage*) OR (interact* W/3 drink*) OR (interact* W/3 food*))	20,899	Food interaction
#8	#7 AND #4	58	Microplastics AND Food interaction
#9	#8 OR #6	1,531	
#10	#9 AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE,"English"))	1,189	Time and language limit

Table D. Search strings on microplastics/nanoplastics: Web of Science platform

Set	Query	Results	Concept
#1	TS= (cutlery OR cup OR cups OR fcm OR FCMs OR "Food Contact Material*" OR fork OR forks OR knife OR knives OR plate OR plates OR spoon OR spoons OR tray OR trays OR ((bag OR bottle* OR cap OR caps OR container* OR film OR glass OR glasses OR package OR packages OR	996,462	FCM

	packed OR packaging) NEAR/5 (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR formula OR fruit* OR meat OR milk OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR "soft drink*" OR softdrink* OR vegetable* OR water OR wine)) OR (beverage* NEAR/3 can) OR (beverage* NEAR/3 cans) OR (beer NEAR/3 can) OR (beer NEAR/3 cans) OR (drink NEAR/3 can) OR (drink NEAR/3 cans) OR (beers NEAR/3 can) OR (beers NEAR/3 cans) OR (drinks NEAR/3 can) OR (drinks W/3 cans) OR teabag OR teabags OR "tea bag*") OR TS=(((bag OR bottle* OR cap OR caps OR container* OR film OR glass OR glasses OR package OR packages OR packed OR packaging) NEAR/5 (plastic OR plastics)) AND (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR formula OR fruit* OR meat OR milk OR recycl* OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR "soft drink*" OR softdrink* OR vegetable* OR "water simulant*" OR wine))		
#2	TI=(CUTLERY OR CUP OR CUPS OR FCM OR FCM OR "FOOD CONTACT MATERIAL*" OR FORK OR FORKS OR KNIFE OR KNIVES OR PLATE OR PLATES OR SPOON OR SPOONS OR ((BAG OR BOTTLE* OR CAP OR CAPS OR CONTAINER* OR FILM OR GLASS OR GLASSES OR package OR packages OR PACKED OR PACKAGING) AND (BEER OR BEERS OR BEVERAGE* OR DAIRY OR DRINK* OR FISH OR FISHES OR FOOD OR FOODS* OR FORMULA OR FRUIT* OR MEAT OR MILK OR "TAKE AWAY" OR "TAKE OUT" OR TAKEAWAY OR TAKEOUT OR "TO GO" OR SOFTDRINK* OR VEGETABLE* OR WATER OR WINE)) OR ((BEVERAGE* OR BEER OR BEERS OR DRINK OR DRINKS) AND (CAN OR CANS)) OR TEABAG OR TEABAGS OR "TEA BAG*") OR TI=(((BAG OR BOTTLE* OR CAP OR CAPS OR CONTAINER* OR FILM OR GLASS OR GLASSES OR package OR packages PACKED OR PACKAGING) AND (RECYCL* OR PLASTIC OR PLASTICS)) AND (BEER OR BEERS OR BEVERAGE* OR DAIRY OR DRINK* OR FISH OR FISHES OR FOOD OR FOODS* OR FORMULA OR FRUIT* OR MEAT OR MILK OR "TAKE AWAY" OR "TAKE OUT" OR TAKEAWAY OR TAKEOUT OR "TO GO" OR "SOFT DRINK*" OR SOFTDRINK* OR VEGETABLE* OR "WATER SIMULANT*" OR WINE))	241,008	
#3	#1 OR #2	1,003,097	
#4	TS= ("MICRO PLASTIC*" OR MICROPLASTIC* OR "NANO PLASTIC*" OR NANOPLASTIC* OR (PLASTIC* NEAR/3 FRAGMENT*) OR (PLASTIC* NEAR/3 PARTICLE*) OR (POLYMER* NEAR/3 FRAGMENT*) OR (POLYMER* NEAR/3 PARTICLE*) OR (SYNTHETIC NEAR/3 PARTICLE*)) OR TI= ((PLASTIC* OR POLYMER*) AND (FRAGMENT* OR PARTICLE*))	80,447	Microplastics
#5	TS= (abrasion OR aging OR ((analys* OR analyt* OR analyz*) NEAR/3 method*) OR ((analys* OR analyt* OR analyz*) NEAR/3 test*) OR ((analys* OR analyt* OR analyz*) NEAR/3 technique*) OR damag* OR degrad* OR "detect" OR "detects" OR "detected" OR "detection" OR "detecting" OR "determined" OR "determination" OR "determine" OR "determines" OR "determing" OR (interact* NEAR/3 beverage*) OR isolat* OR quantif* OR quantit* OR releas*)	22,238,154	Release
#6	#3 AND #4 AND #5	1,407	FCM AND Release AND Microplastics

#7	TS=((interact* NEAR/3 beverage*) OR (interact* NEAR/3 drink*) OR (interact* NEAR/3 food*))	10,514	Food interaction
#8	#7 AND #4	42	Microplastics AND Food interaction
#9	#8 OR #6	1,449	
#10	PY=2015-2100 AND LA=English AND #9	1,152	Time and language limit

Table E. Search strings on oligomer precipitation: Scopus

Set	Query	Results	Concept
#1	TITLE-ABS-KEY ("cutting board*" OR cuttingboard OR cutlery OR cup OR cups OR fcm OR fcms OR "Food Contact Material*" OR fork OR forks OR "kitchen utensil*" OR knife OR knives OR "plastic ware" OR plasticware OR plate OR plates OR spoon OR spoons OR tray OR trays OR ((bag OR bags OR bottle* OR cap OR caps OR container* OR film OR films OR glass OR glasses OR package OR packages OR packed OR packaging) W/5 (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR formula OR fruit* OR meat OR meats OR milk OR milks OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR softdrink* OR vegetable* OR water OR wine OR wines)) OR (beverage* W/3 can) OR (beverage* W/3 cans) OR (beer W/3 can) OR (beer W/3 cans) OR (drink W/3 can) OR (drink NEAR/3 cans) OR (beers W/3 can) OR (beers W/3 cans) OR (drinks W/3 can) OR (drinks W/3 cans) OR (softdrink* W/3 can) OR (softdrink* W/3 cans) OR teabag OR teabags OR "tea bag*") OR TITLE-ABS-KEY(((bag OR bags OR bottle* OR cap OR caps OR container* OR film OR films OR glass OR glasses OR package OR packages OR packed OR packaging) W/5 (plastic OR plastics)) AND (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR formula OR fruit* OR meat OR meats OR milk OR milks OR recycl* OR reus* OR "re usa*" OR "re use*" OR "re usi*" OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR "soft drink*" OR softdrink* OR vegetable* OR "water simulant*" OR wine OR wines))	1,265,978	FCM
#2	TITLE("cutting board*" OR cuttingboard OR cutlery OR cup OR cups OR fcm OR fcms OR "Food Contact Material*" OR fork OR forks OR "kitchen utensil*" OR knife OR knives OR "plastic ware" OR plasticware OR plate OR plates OR spoon OR spoons OR tray OR trays OR ((bag OR bags OR bottle* OR cap OR caps OR container* OR film OR films OR glass OR glasses OR package OR packages OR packed OR packaging) W/5 (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR formula OR fruit* OR meat OR milk OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR softdrink* OR vegetable* OR water OR wine OR wines)) OR ((BEVERAGE* OR BEER OR BEERS OR DRINK OR DRINKS OR softdrink*) AND (CAN OR CANS)) OR TEABAG OR TEABAGS OR "TEA BAG*") OR TITLE(((bag OR bags OR bottle* OR cap OR caps OR container* OR film OR films OR glass OR glasses OR package OR packages OR packed OR packaging) AND (PLASTIC OR PLASTICS)) AND (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR formula OR fruit* OR meat OR milk OR recycl* OR reus* OR "re usa*" OR "re	286,649	

	use*" OR "re usi*" OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR "soft drink*" OR softdrink* OR vegetable* OR "water simulant*" OR wine OR wines))		
#3	#1 OR #2	1,266,191	
#4	TITLE-ABS-KEY (oligomer* AND precipit*)	2,422	Oligomer precipitation
#5	#3 AND #4	40	FCMs AND Oligomer precipitation
#7	#6 AND #4	1	Oligomer precipitation AND Food interaction
#6	TITLE-ABS-KEY((interact* W/3 beverage*) OR (interact* W/3 drink*) OR (interact* W/3 food*))	21,006	Food interaction
#8	#6 OR #4	40	
#9	#8 AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE,"English"))	17	Time and language limit

Table F. Search strings oligomer precipitation: Web of Science platform

Set	Query	Results	Concept
#1	TS= ("cutting board*" OR cuttingboard OR cutlery OR cup OR cups OR fcm OR fcms OR "Food Contact Material*" OR fork OR forks OR "kitchen utensil*" OR knife OR knives OR "plastic ware" OR plasticware OR plate OR plates OR spoon OR spoons OR tray OR trays OR ((bag OR bags OR bottle* OR cap OR caps OR container* OR film OR films OR glass OR glasses OR package OR packages OR packed OR packaging) NEAR/5 (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR formula OR fruit* OR meat OR meats OR milk OR milks OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR softdrink* OR vegetable* OR water OR wine OR wines)) OR (beverage* NEAR/3 can) OR (beverage* NEAR/3 cans) OR (beer NEAR/3 can) OR (beer NEAR/3 cans) OR (drink NEAR/3 can) OR (drink NEAR/3 cans) OR (beers NEAR/3 can) OR (beers NEAR/3 cans) OR (drinks NEAR/3 can) OR (drinks W/3 cans) OR (softdrink W/3 cans) OR (softdrinks W/3 cans) OR teabag OR teabags OR "tea bag*") OR TS=(((bag OR bags OR bottle* OR cap OR caps OR container* OR film OR films OR glass OR glasses OR package OR packages OR packed OR packaging) NEAR/5 (plastic OR plastics)) AND (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR formula OR fruit* OR meat OR meats OR milk OR milks fOR recycl* OR reus* OR "re usa*" OR "re use*" OR "re usi*" OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR "soft drink*" OR softdrink* OR vegetable* OR "water simulant*" OR wine OR wines))	992,429	FCM
#2	TI=("cutting board*" OR cuttingboard OR cutlery OR cup OR cups OR fcm OR fcms OR "Food Contact Material*" OR fork OR forks OR "kitchen utensil*" OR knife OR knives OR "plastic ware" OR plasticware OR plate OR plates OR spoon OR spoons OR tray OR trays OR ((bag OR bags OR bottle* OR cap OR caps OR container* OR film OR films OR glass OR glasses OR package OR packages OR packed OR packaging) AND (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR	241,757	

	formula OR fruit* OR meat OR meats OR milk OR milks OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR softdrink* OR vegetable* OR water OR wine OR wines)) OR ((BEVERAGE* OR BEER OR BEERS OR DRINK OR DRINKS OR softdrink*) AND (CAN OR CANS)) OR TEABAG OR TEABAGS OR "TEA BAG*") OR TI=(((bag OR bags OR bottle* OR cap OR caps OR container* OR film OR films OR glass OR glasses OR package OR packages OR packed OR packaging) AND (PLASTIC OR PLASTICS)) AND (beer OR beers OR beverage* OR dairy OR drink* OR fish OR fishes OR food OR foods* OR formula OR fruit* OR meat OR meats OR milk OR milks OR recycl* OR reus* OR "re use*" OR "re usi*" OR "take away" OR "take out" OR takeaway OR takeout OR "to go" OR "soft drink*" OR softdrink* OR vegetable* OR "water simulant*" OR wine OR wines))		
#3	#1 OR #2	998,977	
#4	TS= (oligomer* AND precipit*)	1,793	Oligomer precipitation
#5	#3 AND #4	31	FCM AND Oligomer Precipitation
#6	TS=((interact* NEAR/3 beverage*) OR (interact* NEAR/3 drink*) OR (interact* NEAR/3 food*))	10,055	Food interaction
#7	#6 AND #4	1	Oligomer precipitation AN Food interactior
#8	#5 OR #7	32	
#9	PY=2015-2100 AND LA=English AND #8	16	Time and language limit

The results of both searches were exported into EndNote 21 (Clarivate), where an initial de-duplication was conducted. Further de-duplication was performed using the SR Accelerator De-duplicator tool[17] (Bond University). The resulting 1711 unique references were then uploaded into DistillerSR software[18] (version, DistillerSR Inc.) for study selection and data extraction.

B.3. Study selection

The selection of scientific studies for inclusion or exclusion was performed using DistillerSR. The process followed a structured two-step approach.

B.3.1. Step 1: Title and abstract screening

- 1711 publications have been screened in this phase of the literature review.
- Each reference was screened independently by two reviewers, based on the information available in the title and abstract, and applying the previously defined inclusion and exclusion criteria.
- Any disagreements were resolved through discussion between the two reviewers. If no agreement was reached, a third reviewer was consulted.

B.3.2. Step 2: Full text screening

- 254 publications have been screened in this phase of the literature search.

[17] https://sr-accelerator.com/#/deduplicator
[18] https://www.distillersr.com/

- The full texts of the publications deemed relevant during the first screening step were assessed in duplicate by randomly assigned reviewer pairs. Four reviewers were involved in this step, and for each publication, a unique pair was formed randomly from this group to ensure independent and balanced evaluation.
- Any disagreements were resolved through discussion between the two reviewers. If no agreement was reached, a third reviewer was consulted.
- Studies selected as relevant during this step were extracted using a data extraction file on DistillerSR in the next step.

B.4. Data extraction

B.4.1. Key data and synthesizing evidence

Data extraction was carried out using DistillerSR. The pool of included publications was divided between two primary reviewers, who each extracted data from their assigned set. A third reviewer was responsible for verifying the overall consistency and completeness of the data extraction file. In total, 122 publications met the scope of this review. For 81 of these, key information was amenable to structured extraction using a dedicated DistillerSR form mapped to the sub-questions (SQ1–SQ6). The remaining 41 publications did not go through the structured but narrative data extraction because the reporting on particle metrics (e.g. size, shape, concentration), methodological details, or study design was insufficiently detailed (see Appendix C). Their main findings were captured in a single narrative text box. This approach preserves their qualitative value for context and gap-identification, while ensuring that the quantitative summaries presented below are based on studies that could be extracted in a consistent and comparable manner. Appendix C provides the publications that are not cited in the references (section 7) and used for the data extraction.

The following key data from the 81 publications were collected through a dedicated structured data extraction form implemented in DistillerSR.

- General information: Origin of the study (EU / non-EU / both / unknown), and country of origin when applicable.
- Type and composition of FCM (SQ1): Type of FCM studied (e.g. bottle, cup, tea bag, containers), material composition (e.g. PET, PE, PP, PVC), and whether the material was virgin or recycled.
- Experimental conditions (SQ1): Test parameters such as temperature, duration, mechanical stress (e.g. abrasion), food simulants, swelling, aging (e.g. UV, oxidation), and whether the conditions are representative of real use.
- Analytical methods and particle characteristics (SQ2): Analytical techniques used (e.g. FTIR, Raman, Nile Red, SEM-EDX), sample preparation protocols, presence of blanks, polymer type(s) detected, particle size, shape (e.g. spherical, irregular), concentration, and composition.
- Contamination and consistency (SQ3): Presence and nature of potential contamination or cross-contamination, and whether the detected particles are consistent with the expected composition of the FCM.
- Mimicking substances (SQ4): Identification of substances (e.g. oligomers, fatty acids, additives) that could mimic MNP, and their potential impact on interpretation.

- Release mechanisms (SQ5): Investigated mechanisms such as physical degradation, chemical degradation, aging, swelling, or carry-over from processing.
- Recycled materials (SQ6): Whether MNP release from recycled materials was investigated, and if so, whether recycling influenced the release.

B.4.2. Identification of uncertainties and evidence gaps

The data extraction process was designed not only to collect data and contextual insights from each publication but also to identify sources of uncertainty and limitations within the available studies. These may include variability in testing conditions, lack of validated analytical methods, insufficient detail in the description of materials or procedures, or issues related to particle identification, potential for artefact formation, and procedural contamination control.

In parallel, the data extraction allowed the identification of publications that, although not fully suitable for quantitative or comparative analysis, highlight structural evidence gaps in the field. These studies may attempt to address the release of MNP from FCM but fell short due to methodological weaknesses, incomplete data, or unclear conclusions.

The distinction between studies suitable for detailed analysis and those primarily indicative of field-level limitations was made based on expert judgement by the reviewers involved in this work. This expert-driven assessment ensures that both types of information, direct evidence and indicative gaps, were captured and appropriately considered during the synthesis phase.

This dual function of the extraction process, data collection and identification of gaps, supports a more comprehensive understanding of the current state of knowledge and helped inform future research and regulatory priorities.

B.5. Additional references not retrieved by the literature search

Eight publications not retrieved by the literature search or beyond the deadline of 20th January 2025 were added manually during drafting of the report to provide additional context and background information. These include two review articles (Ivleva, 2021; Ragaert et al., 2017), a regulatory communication (BfR, 2025), a 'Comment' article (Busse et al., 2020) and four research articles (Habib et al., 2022a, 2022b; Süssmann et al., 2024; Hagelskjær et al., 2025). The reviews were excluded from the literature review as only primary studies were extracted, while the BfR text is not a peer-reviewed publication. The 'Comment' article by Busse et al. (2020) was initially not captured since it appeared to be a letter to the editor, but it does report new findings too and so it was included. The articles by Habib et al., on 'cutting board', were found as references in other publications but they had not been retrieved initially because the term was added only in search strings on oligomers precipitation (Table E, F). The article by Süssmann et al. was not captured because it addresses environmental contamination rather than FCM, but it was considered relevant for discussing Nile Red staining. The article by Hagelskjær et al. was published on 15 January in the Journal "PLOS water", but was not indexed in the database Scopus, thus was not accessible, at the time of the literature search. Because it reports mass-based particles concentrations (one of the very few publications) and it applied a recovery experiment (the only paper), it was considered important to include it in the literature search. It was therefore added manually in DistillerSR.

Appendix C – References extracted but not cited

Appendix C lists the publications that were processed during data extraction but were not cited in the main text. They are grouped as follows: studies for which the full data extraction template was completed (C.1), and studies summarised narratively in a text box, from which only the main information was extracted (C.2).

C.1. Publications with structured extraction

Hadeed, M. D. M., Al-Ahmady, K. K., 2022. Investigate the presence of plastic particles in bottled and reused water bottles for several times and medical feeder bottles. Journal of Pharmaceutical Negative Results, 13, 812-818. DOI: 10.47750/pnr.2022.13.S06.112

Izmirli, S. G., Gökkaya, A., 2024. Microplastic Pollution and Risk Assessment in Packaged Teas in Turkiye. Water Air and Soil Pollution, 235, 19. DOI: 10.1007/s11270-024-07208-z

Jander, J., Hummel, D., Stuermer, S., Monteleone, A., Neumaier, T., Broghammer, F., Lewin-Kretzschmar, U., Brock, T., Knoll, M., Fath, A. S., 2022. Release of Microplastics from Reusable Kitchen Plasticware and Generation of Thermal Potential Toxic Degradation Products in the Oven. Applied Sciences-Basel, 12, 8. DOI: 10.3390/app12052535

Kelishadi, R., Beni, A. A., Ebrahimpour, K., Heidari-Beni, M., 2024. Determination of microplastic release from disposable plastic containers in Isfahan. Chinese Journal of Analytical Chemistry, 52, 7. DOI: 10.1016/j.cjac.2024.100448

Laborda, F., Trujillo, C., Lobinski, R., 2021. Analysis of microplastics in consumer products by single particle-inductively coupled plasma mass spectrometry using the carbon-13 isotope. Talanta, 221, 8. DOI: 10.1016/j.talanta.2020.121486

Li, J., Wang, Q., Cui, M., Yu, S. G., Chen, X. H., Wang, J., 2023. Release characteristics and toxicity assessment of micro/nanoplastics from food-grade nonwoven bags. Science of the Total Environment, 883, 10. DOI: 10.1016/j.scitotenv.2023.163642

Praveena, S. M., Ariffin, N. I. S., Nafisyah, A. L., 2022. Microplastics in Malaysian bottled water brands: Occurrence and potential human exposure. Environmental Pollution, 315, 7. DOI: 10.1016/j.envpol.2022.120494

Tabakoglu, N., Sezer, K., Celik, S., 2024. Microplastics and endocrine-disrupting chemicals released from disposable hot beverage cups and from teabags, and their evaluation in terms of human health safety*. Journal of Elementology, 29, 245-263. DOI: 10.5601/jelem.2023.28.3.3121

Vijay, A., Mohandas, J. L., Dutta-Gupta, S., John, R., 2024. Label-free detection and characterization of secondary microplastics from tea bags. Optical Engineering, 63, 13. DOI: 10.1117/1.Oe.63.1.013101

Wang, H. P., Huang, X. H., Chen, J. N., Dong, M., Zhang, Y. Y., Qin, L., 2023. Pouring hot water through drip bags releases thousands of microplastics into coffee. Food Chemistry, 415, 10. DOI: 10.1016/j.foodchem.2023.135717

Winkler, A., Fumagalli, F., Cella, C., Gilliland, D., Tremolada, P., Valsesia, A., 2022. Detection and formation mechanisms of secondary nanoplastic released from drinking water bottles. Water Research, 222, 12. DOI: 10.1016/j.watres.2022.118848

Xu, C., Hu, J. L., Dong, B., Lin, Q. B., Wu, S. L., Chen, J., Wang, J., Li, D., Zhong, H. N., 2024. Safety assessment of polypropylene self-heating food container: The release of microplastics and volatile organic compounds. Food Packaging and Shelf Life, 44, 9. DOI: 10.1016/j.fpsl.2024.101307

Xu, J. L., Lin, X. H., Hugelier, S., Herrero-Langreo, A., Gowen, A. A., 2021. Spectral imaging for characterization and detection of plastic substances in branded teabags. Journal of Hazardous Materials, 418, 15. DOI: 10.1016/j.jhazmat.2021.126328

Zhou, G. Y., Wu, Q. D., Tang, P., Chen, C., Cheng, X., Wei, X. F., Ma, J., Liu, B. C., 2023. How many microplastics do we ingest when using disposable drink cups? Journal of Hazardous Materials, 441, 8. DOI: 10.1016/j.jhazmat.2022.129982

Zhou, X. J., Wang, J., Ren, J. F., 2022. Analysis of Microplastics in Takeaway Food Containers in China Using FPA-FTIR Whole Filter Analysis. Molecules, 27, 10. DOI: 10.3390/molecules27092646

Zhu, J. Q., Dong, X. W., Zhao, N., Jiang, S. T., Jin, H. B., 2023. Microplastics in polystyrene-made food containers from China: abundance, shape, size, and human intake. Environmental Science and Pollution Research, 30, 40084-40093. DOI: 10.1007/s11356-022-25093-z

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