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Comparison of microplastic type, size, and composition in atmospheric and foliage samples in an urban scenario☆

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ABSTRACT

The rising trend of plastic production in last years and the inadequate disposal of related waste has raised concerns regarding microplastic-related environmental issues. Microplastic particles disperse by means of transport and deposition processes to different ecosystems and enter food chains. In this paper, atmospheric deposition and foliage samples of two species (i.e., *Hedera helix* and *Photinia glabra*) were collected and analysed for the quantity and identity of microplastics (MPs). A preliminary methodology to treat foliage samples and subsequently identify MPs using a quantum cascade laser IR spectrophotometer is presented. The treatment of airborne samples involved filtration, mild digestion, concentration, and transfer onto reflective slides whereas that for foliage involved washing, concentration, and transference of putative MPs onto reflective slides. Fibers and fragments were differentiated according to their physical features (size, width, height, etc.) and calculating derived characteristics (namely, circularity and solidity). The preliminary results obtained suggest a good agreement between atmospheric-deposited and foliage-retained MPs, showing the capability of leaves to act as passive samplers for environmental monitoring.

1. Introduction

Plastic contamination in the environment largely increased in the last few decades as a result of population growth and excessive use of polymers and their inadequate waste management. Plastic is among the most convenient commodity material since it is utilized for the production of disposable products and envelopes. When plastic polymers reach the environment, their residues degrade due to erosion, solar radiation, weathering, and microorganisms and break into smaller particles. Additionally, microplastic particles (MPs) might be released directly into the environment from primary sources, such as personal care products, synthetic textiles, and tyres (Boucher and Friot, 2017). MPs can be defined as solid plastic particles insoluble in water with dimensions between 1 μm and 1000 μm (=1 mm), being those between 1 and 5 mm "large microplastics", (ISO, 2020) whose composition is dominated by carbon, hydrogen, and heteroatoms like oxygen, nitrogen, sulfur, and chlorine.

As concerns about MPs increased over the last decade so did the attention devoted to their identification and quantitation in different environmental compartments. Thus, the presence of MPs in marine environments, some organisms and soils and sediments has been broadly studied (Hernandez-Gonzalez et al., 2018; Novillo et al., 2020; Thompson et al., 2004), as well as in algae and plankton (López-Rosales et al., 2021, 2022b). However, much less studies were focused on atmospheric microplastics (AMPs) despite it is known that they can be transported over long distances in the form of suspended atmospheric particles (Allen et al., 2019;(Allen et al., 2021). In this way, they may contribute to terrestrial and vegetation contamination. Luo et al. (2022) provided a recent review on the availability of procedures for the different working stages: sampling, sample treatment, and particle identification. Another general review was conducted by Shao et al. (2022) on the possible sources of AMPs and their spatial and temporal distribution. It turned out that population density and industrialization are important factors to explain the distribution of AMPs since a higher level of AMPs was seen in urban environments when compared to rural areas. Also, more plastic fibers and particles were found indoor than

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outdoor (Shao et al., 2022). A recent study looking for atmospheric sources that may threaten humans because of inhalation of their associated MPs (Munyaneza et al., 2022) evaluated different pathways such as households, industry, traffic, and landfills and demanded urgent methodological developments and standardization of sampling and analysis. More recently, a method to measure reliably AMPs collected with atmospheric bulk deposimeters (wet and dry deposition) was proposed, along with some criteria to select the best digestion method and to obtain high confidence spectral identifications of MPs using a quantum cascade laser in the medium IR spectral region (QCL-LDIR) (López-Rosales et al., 2024). Regarding plants, many studies demonstrated that leaves of terrestrial vegetation could act as passive air samplers for gaseous organic compounds. This was shown to depend on the plant/air partitioning coefficient (Giráldez et al., 2022; Kömp and McLachlan, 1997; Nizzetto et al., 2008). Additionally, many studies investigated the accumulation of atmospheric particulate matter (PM) on leaves, indicating the capability of leaves to "filter" the atmosphere (Terzaghi et al., 2013; (Cai et al., 2017)(Chávez-García and González-Méndez, 2021)). However, little is known about the capability of plant leaves to filter the atmosphere for MPs (Liu et al., 2020; Li et al., 2022; Leonard et al., 2023; Xu et al., 2024). In particular, there is a lack of studies investigating AMP deposition on leaves with time as well as the possibility of using plant leaves as passive deposimeters, or passive samplers, in substitution or to complement the standard AMP deposition measurements for environmental monitoring. Hence, the aims of the present work were to: i) develop a preliminary protocol for sampling, sample treatment, and identification of MPs in leaf samples; ii) quantify MPs in air and leaf samples (either fragments and fibers), and iii) establish a preliminary comparison between the deposition patterns observed for air and leaf samples to provide hints on the possibility of using leaves as passive AMP samplers.

2. Materials and methods

2.1. Apparatus

The relatively novel instrumental technique based on the use of a quantum cascade laser (QCL) in the medium IR spectral region (8700 LDIR from Agilent Technologies, USA), 1800-975 cm^{-1} region, along with reflective slides (MiRR, Kevley Technologies, Chesterland, USA) was employed to characterize MPs. A number of physical parameters derived from the shape of the particles, such as aspect ratio, circularity, and solidity were used to semi-automatically categorize the MPs as fibers or fragments. The QCL-LDIR operating parameters were the same for all samples, including the blanks. The measuring size range was set from 20 μm to 5000 μm, sensitivity was set to 3 (Agilent Clarity 1.0. version) and speed scan was set in the default mode.

Further, a Leitz Wetzlar stereomicroscope (10× ocular and manual adjustment of the objective zoom up to 5×, total magnification 50×); a 3000867 Selecta ultrasonic bath (Barcelona, Spain); a Syncore-Plus automated evaporation system (Büchi, Switzerland), equipped with a V-800/805 vacuum controller and an R-12 vacuum line, and 12 dedicated glass containers (residual volume 1.0 mL), were employed. A Rotabit P incubation system (Selecta, Spain), with adjustable temperature and trembling controls, and a Pobel vacuum filtration system equipped with a Millipore vacuum pump (Millipore, Ballerica, MA model WP6122050) were used as well.

2.2. Reagents and materials

The reagents employed were 2 % SDS aqueous solution (sodium dodecyl sulfate, ≥98.5 % purity, Sigma-Aldrich), Triton X-100 (Sigma-Aldrich), hydrogen peroxide (30 %, Sigma-Aldrich), and 96 % ethanol (Merck). Ultrapure MilliQ-type water (18 MΩ·cm resistivity) was from a Direct-Q 3-V Millipore (Molsheim, France) system, collected and used daily. The 20 μm mesh size (open bore, square weave mesh type) metallic filters were from Bopp & Co. A.G: (Switzerland) and the 1000 μL pipette tips were from Eppendorf (Hamburg, Germany).

2.3. Samples

Air samples were collected in January 2022 in an air monitoring station located in a semi-urban location close to the city of A Coruña (Instituto Universitario de Medio Ambiente, IUMA). The location and geographical coordinates of the sampling site are shown in Fig. 1. The region (A Coruña, Galicia, NW Spain), has an Atlantic climate, with rain events spread throughout the whole year which yielded a total annual precipitation ca. 1000 mm, though less frequent in summer (July–September, 74.2–148.8 mm). The region is often overcast, with moderate-strong winds from the Atlantic depression. The sample location for the foliage corresponds to a semiurban site with some hourly peaks of traffic vehicles (mostly, university-related) although low traffic density during the day. On the weekends the amount of traffic is negligible. A relevant issue is that the collection site is located at the top of a little hill SW of the city and wind blows frequently from the city to that point.

2.3.1. Atmospheric sampling

Two Depobulk (LabService Analytica, Italy) passive samplers (bulk air deposition samplers, BAS) were placed at a 2.5 m height on top of the air monitoring station, without nearby obstacles, and at ca. 20 m of the closest roadside. They were retrieved after a month in order to determine the total atmospheric deposition (dry and wet deposition) associated to January 2022. The passive samplers are constituted by 0.22 m diameter (0.038 m^2) glass funnels and 10 L ISO standardized glass collecting bottles, surrounded by a Teflon shield, see Fig. 1.

2.3.2. Foliage sampling

Fully developed (approximately one year old) and undamaged leaf samples of two species, *Hedera helix* (from now on referred to as HH) and *Photinia glabra* (from now on referred to as PG) (Fig. 1) were collected in the entrance street to Campus da Zapateira of the University of A Coruna (UDC) in November 2022.

The reasons for the difference in the sampling period, compared to the atmospheric samples, were the need for avoiding gardening and maintenance works and, after that, the time required for the leaves to develop fully. In this way, undue particle (MPs) sources were avoided and it was expected that sufficient deposition of particles to observe the potential retention of AMP on the leaf surfaces would be obtained. Hence, the numbers of fibers/fragments were expected to be measured reliably. For example, PM accumulation and aggregation of particles was observed by Terzaghi et al. (2013) at the end of a whole season. Furthermore, note that both months correspond to late fall-early winter, which exhibit very similar weather patterns (Southerly winds, abundant rain, etc.) thus making the comparisons possible.

For each species, five to six leaves were sampled, at about 0.5–1 m height, from different parts of the plants and at different positions to collect a representative average sample of AMPs deposition. Leaf samples were wrapped with aluminum foil and carried to the laboratory in freezer bags.

2.4. Sample treatment and measurement methods

2.4.1. Atmospheric samples

The Depobulk air samplers (BAS) containing the one-month atmospheric deposition were washed thoroughly with MilliQ water and the solutions were filtered through 20 μm stainless steel filters. The filters were mild-digested for 48 h using 2 % SDS and hydrogen peroxide (in such amount that the final concentration in the working solution was 15 %). A transfer protocol of the particles to the reflective slides, validated previously (López-Rosales et al., 2022a), was then undergone. In brief, the filters were washed directly into dedicated Büchi glass tubes using 40 mL of 98 % ethanol. Particles were released from the surface of the

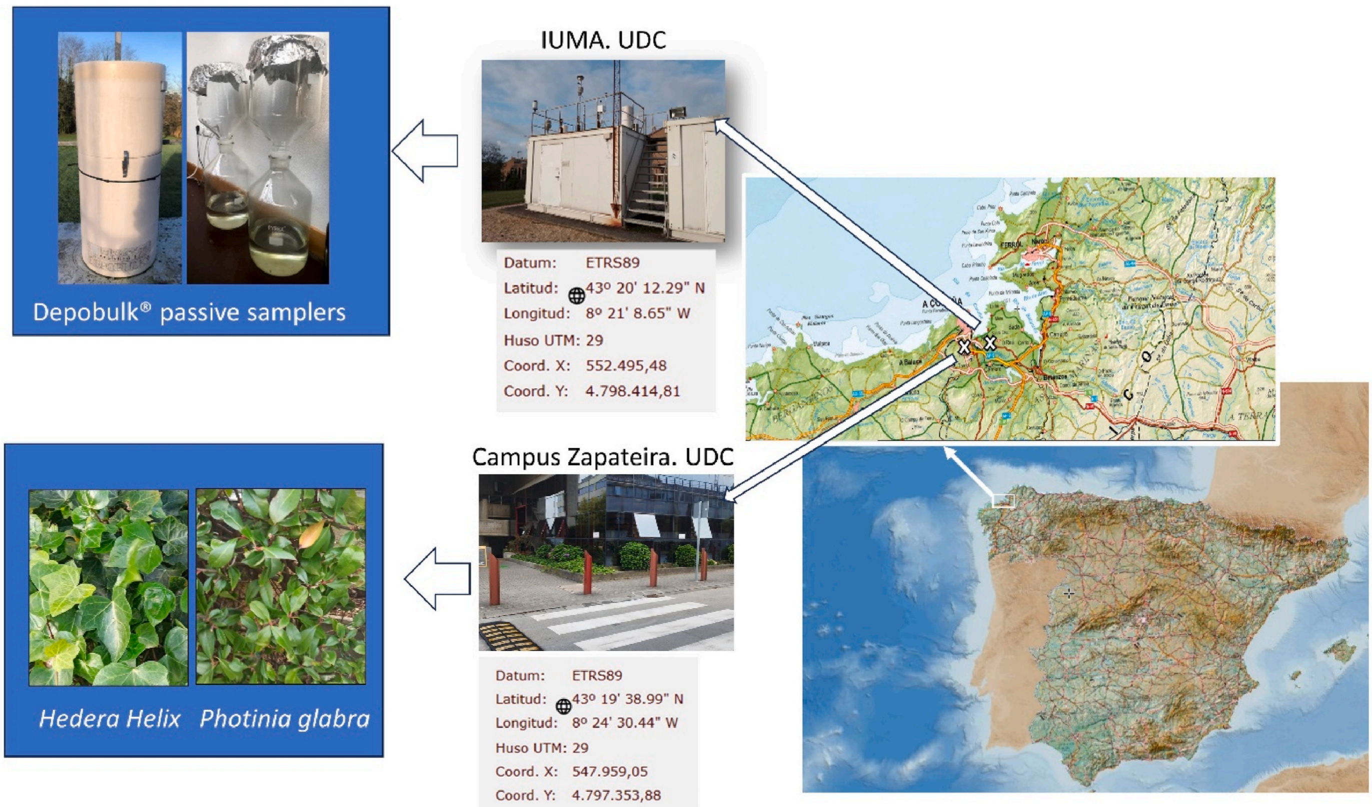

Fig. 1. Location of the semi-urban sampling sites, close to the city of A Coruña, NW Spain.

filters using an ultrasonic bath (30 min, with different frequencies: 37 and 80 kHz, 15 min each; temperature <35 °C).

The suspensions thus obtained were located into an automatic evaporation Syncore system at a temperature of 40 °C and evaporated until ca. 2 mL. These remains were transferred onto a microscopy reflective slide, as required for the QCL-LDIR system. The Büchi evaporation glass tubes were washed twice with ethanol, concentrated in the Syncore and the remaining volume was transferred onto the reflective

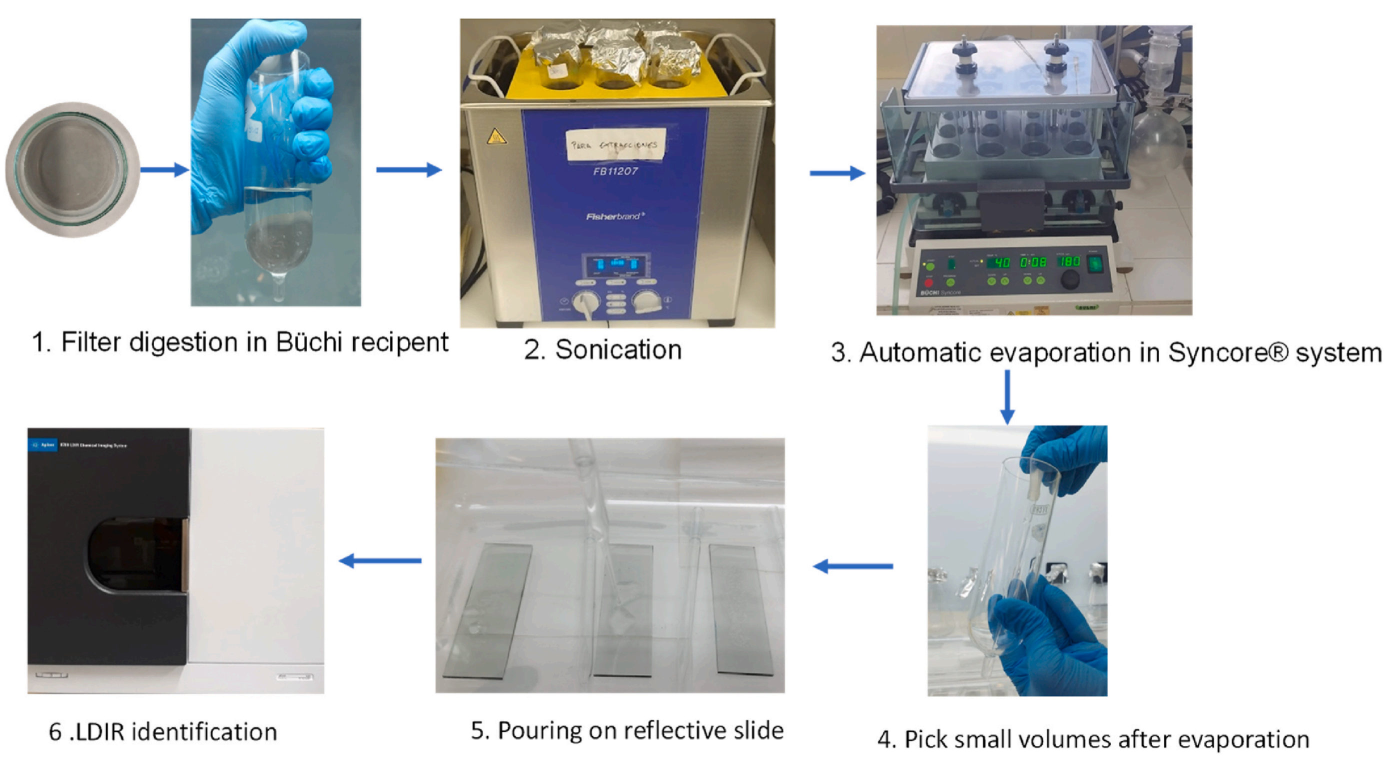

Fig. 2. Scheme of the main steps to treat airborne-deposited particles (once they were mild digested) and leaf (washed) samples.

slides where the sample itself was. The slides were kept in a closed fume hood at room temperature until completely dried prior to their measurement. The overall procedure is schematized in Fig. 2. This procedure was validated elsewhere, with recoveries ranging 82–90 % for fragments and 62–73 % for fibers (considering the PP, PS, PE, PET, PA, PVC and PET polymers), in line with other published studies (López-Rosales et al., 2024).

2.4.2. Foliage samples

The mild procedure to release the MPs from the foliage samples implied addition of the leaves to rotating (130 U/min) 500 mL glass beakers containing 300 mL of Milli-Q water and 30 mL of 0.1 % Triton-X100. This procedure was adapted from a previously validated one for seaweeds (López-Rosales et al., 2022b) and it agrees with He et al. (2023) as they indicated that a mere rinsing with water was ineffective to remove plastic particles from leaves of lettuce. Sonication exhibited four times greater efficiency, while washing with a surfactant proved to be the most effective method, increasing the efficiency by ca. 7 times. After 1 h each leaf was withdrawn with metal tweezers and washed over the beaker using a 0.02 % solution of Triton X100. Additional details on the validation of this protocol can be found elsewhere, with recoveries ranging 64 % (fibers)-87 % (fragments) for PE, PP, PS, PET, PA and PVC (López-Rosales et al., 2022b). The resulting suspensions after washing all leaves (1 L) were vacuum-filtered through a 20 μm stainless steel filter. Then, the particles were released from the metallic filters by washing them thoroughly with 50 mL of 98 % ethanol over a Büchi glass tube. Further, the tubes with the filters were sonicated for 30 min at different frequencies (37 and 80 kHz, 15 min each), at < 35 °C. Then, the filter was removed and washed again with 25 mL of ethanol. Subsequent steps to reduce the volume of the suspension using a Syncore system and its final withdrawal were as for the airborne samples. Finally, the contents of the Büchi tubes were evaporated to ca. 1 mL and the final remains were transferred to the reflective slides for their measurement.

2.5. Quality control

All glassware was washed with alkaline soap (Extran MA01) for 48 h and rinsed with abundant tap and MilliQ water. All reflectance slides were pre-cleaned with ethanol. Glassware and other materials used during the analysis were covered with aluminium foil during storage and use. The entire experiment was performed inside a fume hood. During operation, cotton clothing was used as far as possible to prevent contamination by microplastic fibers. Two procedural blanks were considered along with each sample batch, according to protocols proposed elsewhere (Hermsen et al., 2018). The criterion for polymer identification (match index with the spectral library) in the LDIR system was set higher than 90 % (López-Rosales et al., 2024). An example of the relevance of such match requisite is available in **Figure SI–1**.

Calculation of AMPs deposition on leaves referred to the total surface area of the leaves (MPs·m^{-2}). Microplastic fragments and fibers were blank-corrected (i.e., the number of each type of AMPs in the procedural blanks subtracted from the raw counting). A table with fiber and fragment counts (per polymer and per size) detected in blanks is available in the Supporting Information (Table SI-1).

3. Results and discussion

3.1. Microplastics in air and foliage

3.1.1. Total amount and shape

Total AMPs in air, HH, and PG samples amounted to 73, 67 and 101 items, respectively (these are bulk depositions, after subtracting blanks, without further normalization). Since a plain numerical comparison between the bulk air sampler and the leaves is not possible (not even normalizing by their surface) given the different accumulation time (1 month for BAS, several months for leaves), further comparison between BAS and leaves will be done by comparing their fingerprint or the percentual composition by polymer type.

In our studies, fragments were more abundant than fibers, the former representing 73–92 % of the overall AMPs. The accumulation of AMPs per surface of leaves corresponds to 2735 MP·m^{-2} and 6235 MP·m^{-2} for HH and PG leaves, respectively, showing a higher accumulation ability for PG than HH. AMPs in terrestrial environments derive mainly from urban areas, particularly city dust, runoff and road dust (Campanale et al., 2022). Agricultural practices ranked second. AMP total levels varied largely with location, with fibers being the dominant type of particles indoor (Bhat, 2023). Few studies are currently available in the literature on AMP leaf uptake and reporting on AMPs abundances on leaves. In turn, their values extend through several orders of magnitude (Fig. 3 and Table 1). The difference can be ascribed to many factors including sampling site type (i.e., urban, semiurban, rural, etc.) and therefore AMP air source and levels, plant species, meteorological parameters (i.e., rainfall and windspeed) as well as AMP detection method (including the threshold/matching criteron).

For example, Leonard et al. (2023) investigated the variability of AMPs on leaves of five tree species collected in 19 sites in Los Angeles (residential, commercial and park areas) at three different heights (<0.6 m, 0.6–1.2 m, >1.2 m). As expected, different leaf types exhibited significant variations in microplastic concentrations (1400–250000 MP·m^{-2}), suggesting that leaf surface properties, such as hydrophobicity and roughness, influence retention. Maximum levels were found in leaves collected between 0.6 and 1.2 m height, indicating that the position of the leaf above the ground could affect the AMPs amounts on leaves. AMPs were measured staining with Nile red which was able to detect AMPs <10 μm by FTIR microscope (60 % match criterion) but they could characterize AMPs only >20 μm. Xu et al. (2024) investigated AMPs adsorbed on leaves on three species collected at 2 m height in urban, suburban, and rural sites in Beijing. They used the same instrument as the present study (i.e., QCL-LDIR imaging system) although considering a quite low spectral match criterion, >65 %, which nowadays is not recommended. AMPs abundance was higher than that measured in the current study, ranging from 18,900 to 60,500 MP·m^{-2} depending on plant species, sampling site and period (i.e., May vs September). Liu et al. (2020) measured deposition of AMPs on terrestrial plants (five species, at 40 cm height) in Shanghai and Liandao Island (China) characterized by different population densities. Their abundance, quantified with a μFTIR spectrometer (match index >60 %) ranged from 700 MP·m^{-2} to 1900 MP·m^{-2}, a factor of 3–8 lower than that of the current study. Li et al. (2022) investigated the uptake/capture of MPs by the leaves of six mangrove species sampled in the Beibu Gulf with a micro-Raman spectrometer. The findings revealed that the abundance of MPs captured by mangrove leaves increased progressively from the seaward to landward zones, with values for non-submerged leaves in the range of 900–2400 MP·m^{-2}, which are two-to sixfold lower than those of the current study.

3.1.2. AMPs size class distribution in leaves

Fig. 4 shows the size distribution of the polymeric particles (fibers and fragments) as a function of their size, for both types of leaves. Tyre wear fragments were excluded from the graph because they represent an important fraction in leaf samples and will be discussed in the next section.

For leaves the amount of fragments is higher than the amount of fibers, by more than an order of magnitude; fragments represent 73–92 % of total AMPs. The size distributions on leaves are similar to those in air.

Studying the air sampled with the Depobulk system (BAS, Table SI-2 for raw number, blank subtracted, or Table SI-3 for deposition rates), PG and HH data it can be observed that fibers are generally a small fraction of the total particles, 14 %, 8 % and 27 % respectively. This shows that leaf samples, as well as BAS, receive mostly fragments and not fibers, being the ratio basically dependent on the number of small fragments, which constitute the largest number of particles. This also confirms the

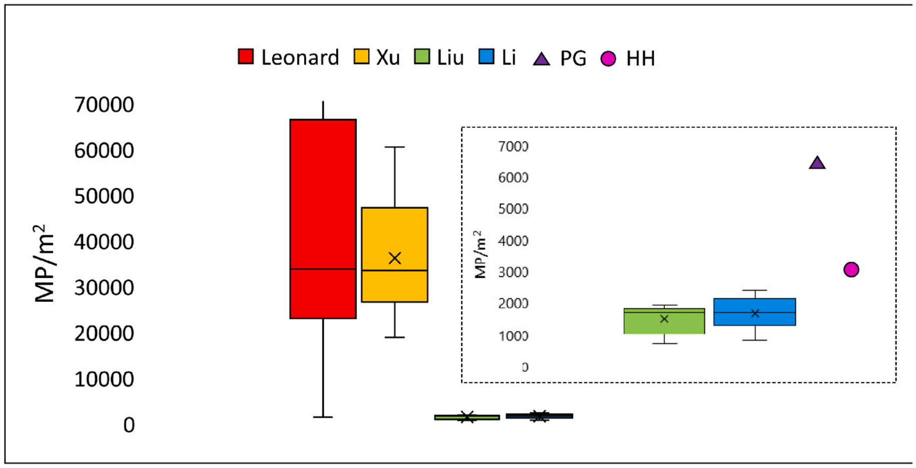

Fig. 3. Literature comparison of AMP leaf concentrations (MP·m^{-2}). References: (Leonard et al., 2023; Xu et al., 2024; Liu et al., 2020; Li et al., 2022); PG: Photinia glabra; HH: Hedera helix. Smaller box plots are magnified in the inset on the right, where PG and HH are also presented.

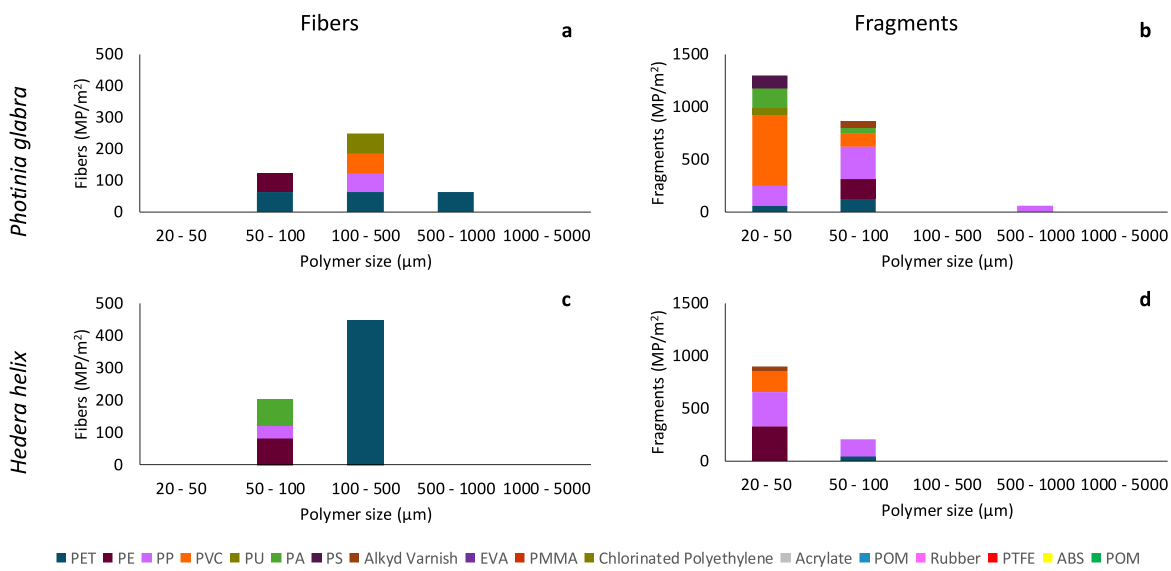

Fig. 4. Distribution of fibers (a, c) and fragments (b, d) by size, polymer type, and species, Photinia glabra and Hedera helix leaves. Particle tyres were excluded. PET (poly(ethylene terephthalate)), LDPE/HDPE (low/high-density polyethylene, together considered as PE), PP (polypropylene), PVC (polyvinyl chloride), PU (polyurethane), PS (polystyrene), EVA (ethylene vinyl acetate), PMMA (poly(methyl methacrylate)), PA (polyamide), PTFE (Teflon), ABS (acrylonitrile butadiene styrene), POM (polyoxymethylene).

similar composition of the air masses during the sampled months and the capability of plant leaves, as passive samplers, to retain AMPs with ratios similar to bulk samplers.

The number of fibers is larger in the medium size range (100–500 μm). For air, they represent 80 % of total fibers and ca. 11 % of all AMPs (Table SI-2 and Table SI-3). For the leaves, this range accounts for 63–72 % of total fibers. The 50–100 μm fibers represent 20 % of the fibers in air, and ca. 7 % of all AMPs (in HH and PG they are 25–28 % on average). Small fragments dominate the smallest fraction (20–50 μm) accounting for 100 % of the particles in this range (and 56 % of all AMPs), whereas for HH and PG they represent 65–67 % (Fig. 4, Table SI-4, Table SI-5 and Table SI-6).

Small particles (20–100 μm) are more abundant in air since they tend to remain suspended on it while the coarser and heavier ones tend to settle down (Munyaneza et al., 2022). Similarly, big particles deposited on leaves could be more susceptible to wind resuspension and, mostly, rain wash off.

Table SI-3

3.1.3. Constituent polymers

Fig. 5 shows the major polymeric composition of the MPs for airborne and leaf samples. As mentioned before, tyre wear fragments in leaf samples are an important fraction of the deposition, due to the fact that leaf samples were collected in a location close to a road (about 1 m away), while the bulk deposition air samples were collected at about 20 m away from the closest road. Tyre wear particles were mostly fragments. They were present mainly in the smaller range (20–50 μm) where they represent for ca. 45–70 % of the total MPs. In the medium range (50–100 μm) they account for about 20–40 %. For the larger sizes (100–500 μm) they were only about 5–15 %, and less than 10 % were fibers in this range. In airborne deposition (BAS) no tyres were found among the fibers; only as fragments (ca. 13 % of all fragments).

Aside from tyre wear particles, the predominant polymers in all samples were PP, PE, PVC, PET, PS and PA. All of them are of common use, and they constitute the basis of the primary production of many commodities which can erode and/or degrade while in use or after their release. Curiously, the distribution of the tyre wear particles as a function of their size was not observed for the passive air sampler, but that

Table 1
Location, period and sampling details for the currently available studies dealing with AMP determination on leaves.

Study	Location	N° of sites	Type of site	Period	N° of species	Species	N° of leaves	Sampling height	Type of analyses	Screening Threshold
Current study	La Coruña (Spain)	1	semi-urban	November 2022	2	*Photinia glabra, Hedera helix*	5–6	0.5-1 m	LDIR	>90%
Liu et al. (2020)	Shanghai and Liandao Island (China)	2	dense (university, roadside, parks) vs sparse human population	March–April 2018	5	*Pittosporum tobira, Camellia japonica, Aucuba japonica, Buxus sinica, Trachelospermum jasminoides*	3–18	0.4 m	μFTIR	>60%
Li et al. (2022)	Beibu Gulf (China)	6	village, urban and tourist sites	July–August 2020	6	*Aegiceras corniculatum, Vicennia mariana, Bruguiera gymnoihiza, Aegiceras corniculatum, Vicennia mariana, Rhizophora stylosa*	at least 30	not available	micro-Raman spectrometer	not available
Leonard et al. (2023)	Los Angeles (USA)	19	residential, commercial, and parks	February 2022	5	*Acer saccharum, Rhus ovata, Buxus sempervirens, Leymus condensatus, Chamaerops humilis*	9–30	<0.6 m, 0.6–1.2 m, >1.2 m	FTIR, Nyle red	>60%
Xu et al. (2024)	Beijing (China)	3	urban, suburban, and rural	May and September 2022	3	*Platycladus orientalis* L. , *Juglans regia* L., *Ulmus pumila* L.	3–4	2 m	LDIR	>65%

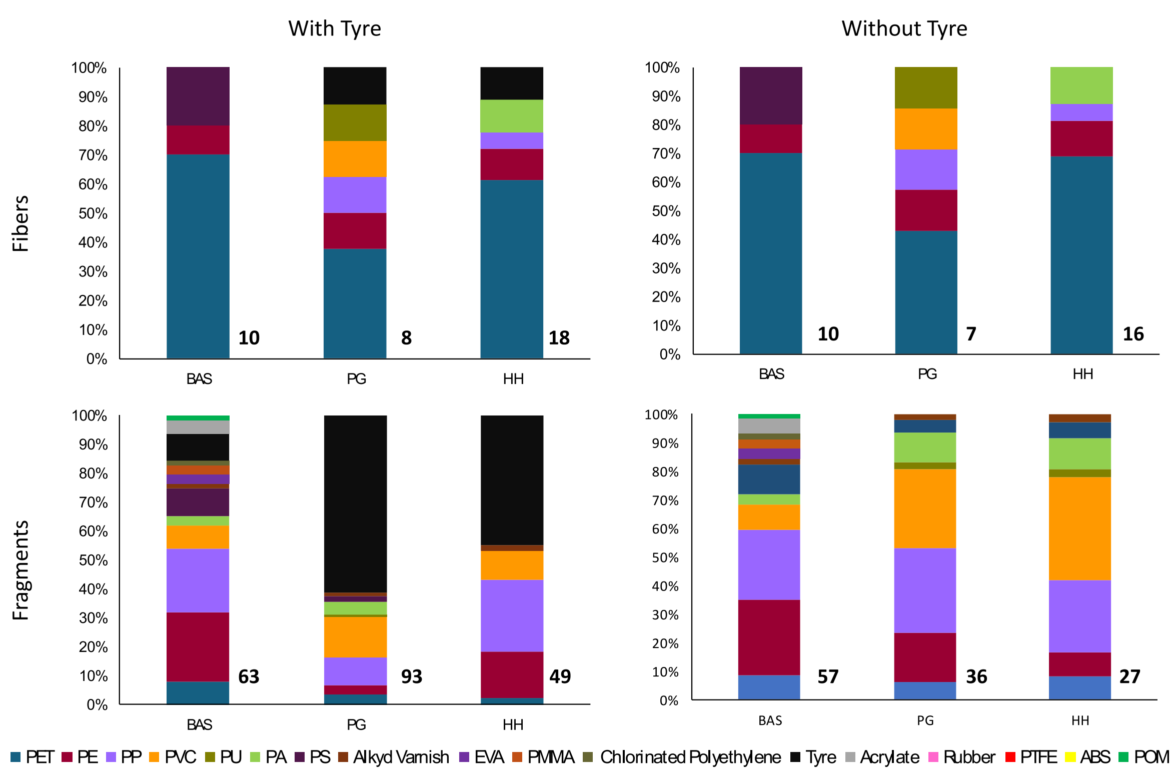

Fig. 5. Depobulk air sampler (BAS), Photinia glabra (PG) and Hedera helix (HH) microplastic polymer composition (fibers: top; particles: bottom): PET (poly (ethylene terephthalate)), LDPE/HDPE (low/high-density polyethylene, together considered as PE), PP (polypropylene), PVC (poly(vinyl chloride)), PU (polyurethane), PS (polystyrene), EVA (ethylene vinyl acetate), PMMA (poly(methyl methacrylate)), PA (polyamide), Rubber, PTFE (Teflon), ABS (Acrylonitrile butadiene styrene), POM (Polyoxymethylene). The numbers at the bottom of the columns represent the total number of MPs.

might be caused by the higher distance from roads and the different sampling height. However, the relatively comparable fingerprints among the different samplers (BAS and leaves), once tyre wear fragments were excluded, reveals that they receive aerially transported microplastics deriving from the same major sources, since they generally receive wind that blows from the main city (A Coruña). On the other hand, although some specific accumulation patters can be observed for the two species, the results confirm the suitability of leaves to evaluate the relative polymer composition of aerial deposition, in other terms to function as passive air samplers. In addition, the association of tyre wear fragments and closeness to roads (and so traffic) reveals the capability of plant leaves to show fine details in the spatial distribution of AMPs (in particular tyre wear particles).

3.2. Comparison between MPs and particulate matter deposition

The measurement of AMPs is a relatively novel topic. Hence, very few studies are available about the uptake of MPs by leaves (Campanale et al., 2022; Li et al., 2020; Mateos-Cárdenas et al., 2021), therefore an in-depth literature comparison is not feasible. However, it has recently been pointed out that AMPs share many common features with traditional airborne particulate matter (PM), like shape, size, aerodynamic properties, etc. Therefore, the knowledge about PM uptake/release by plant leaves can be used to assess the interactions between AMPs and leaves (Bi et al., 2020). For example, it is well known that the physical characteristics of a leaf (e.g., roughness, hairiness, petiole length, etc.), its cuticle chemical composition (e.g., quantity and quality of waxes) (Di Guardo et al., 2003) and the cuticle structure (e.g., thickness, morphologies) influence the removal efficiency of PM from air by different plant species (Chen et al., 2017; Dzierżanowski et al., 2011; Liu et al., 2018; Sæbø et al., 2012). Concerning the PM distribution on the leaf surface, the PM10 fraction (particles <10 μm) is generally the most abundant one (Teper, 2009; Terzaghi et al., 2013, 2013; Wang et al., 2006); while larger particles (>10 μm) are easily washed off during rain events and resuspended by wind, while the smallest particulate matter, PM2.5 (particles <2.5 μm), represents the fraction of particles that can be encapsulated in the leaf cuticle and therefore are hardly removed by rain and wind (Dzierżanowski et al., 2011; Terzaghi et al., 2013). PM was also shown to mediate the transfer of organic contaminants to the leaf cuticle (Terzaghi et al., 2013), similarly to what happens with MPs found in the aquatic ecosystems, which can adsorb several environmental contaminants acting as vectors for those compounds to aquatic organisms (Akdogan and Guven, 2019; Katsumiti et al., 2021). Finally, if a rough comparison between the size distribution of PM in air and on leaf is done, plant leaf surfaces seem to act also as aggregation surfaces for smallest particles (<1 μm), which represents the most abundant fraction of particles in air. This might also happen for AMPs and air nanoplastics (ANPs) and they have recently attracted increasing attention as they may represent a pathway for the transference of contaminants to crops (Sun et al., 2021).

Although AMPs and PM could share similar behaviors, their different physical characteristics (e.g., the more lipophilic surface of AMPs), composition (e.g., organic substances) and shape (e.g., fibers) can differently affect their fate. Therefore, further studies are necessary to identify the driving factors in influencing leaf uptake and release of AMP and, therefore, their environmental fate, including their transfer from air to soil through the forest filter effect, as well as their degradation and accumulation in terrestrial food web.

4. Conclusions

This study provides a preliminary approach to treat leaf samples in order to determine the number and type of airborne microplastics present on their surface and use them as passive air samplers to detect this type of pollutants in the atmosphere. A similar fingerprint for MPs was identified in leaves and in the atmospheric deposition, and fragments represented >80 % of total MPs. The number of fibers was higher in the 100–500 μm size range, whereas fragments were more abundant in the 20–50 μm size range. The results were in line with some of the few works available in the literature. Additionally, in the current work the determination of the chemical composition of the MPs for each size fraction revealed that PET, PP, PE, PVC, PS and PA were the most frequently detected polymers (excluding tyres), representing the polymers of common use. However, there are still challenges to address. For example, how to perform reasonable evaluations of the analytical recoveries on leaves, as there is no reference material, or how to match the periods of atmospheric collection and the accumulation time of the leaves. Moreover, additional efforts are necessary to understand the environmental fate processes involving the interactions between MPs and vegetation (e.g., uptake, release, degradation, food web accumulation, etc.).

CRediT authorship contribution statement

Parisa Falakdin: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Adrian Lopez-Rosales:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Jose Andrade:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Elisa Terzaghi:** Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization. **Antonio Di Guardo:** Writing – review & editing, Investigation, Conceptualization. **Soledad Muniategui-Lorenzo:** Writing – review & editing, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2024.123911.

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