



HEALTH SCIENCES

First evidence of microplastic accumulation in placentas and umbilical cords from pregnancies in Brazil

CAMILA WANDERLEY L. OLIVEIRA, LAIS F.A.M. OLIVEIRA, JACOB GARCIA, RODRIGO B. WEINGRILL, JOHANN URSCHITZ, SAMUEL T. SOUZA, EDUARDO JORGE S. FONSECA, STEPHANIE OSPINA-PRIETO & ALEXANDRE U. BORBELY

Abstract: Microplastics (MPs) production and degradation are becoming a global concern. They accumulate across diverse environments, animals, and human tissues, closely linking to emerging environmental health impacts. In the Brazilian population, no evidence yet of accumulation in pregnant women's placenta or umbilical cord. In this pilot cross-sectional, observational study, we analyzed the presence, size, and composition of MPs isolated from placentas (n=10) and umbilical cords (n=10) from Maceio pregnant women. Under a plastic-controlled protocol, samples were digested with 10% KOH solution, glass-filtered, and retained particles were then analyzed by Raman spectroscopy. A total of 229 MPs were identified across all samples, including 110 in placental tissues and 119 in umbilical cord tissues. The predominant polymers were polyethylene (PE), polyamide (PA), polyethylene vinyl acetate (PEVA), polyurethane (PU), and polypropylene (PP). Our results demonstrated for the first time the accumulation of MPs in the placentas and umbilical cords of Brazilian pregnant women. This accumulation suggests that pregnant women in Maceio, Brazil, are likely experiencing microplastic (MP) exposure similar to global trends, emphasizing the importance of studying the mechanisms that facilitate the transport of MPs and related chemicals across the placental barrier.

Key words: Microplastics, Placenta, Umbilical Cord, Pregnancy, Alagoas.

INTRODUCTION

In 2022, global plastic production reached an astonishing 400.2 million tons (Europe 2023), with a substantial portion of plastic waste remaining unrecycled worldwide (Croxatto Vega et al. 2021, Europe 2023). This rising production, coupled with inadequate waste management, is a primary contributor to plastic pollution, resulting in serious environmental effects and potentially affecting human health. Microplastics (MPs) are defined as plastic particles of 1 μ m and 5 mm that can originate from direct industrial production (primary MPs) or the breakdown of larger plastic items, secondary MPs (Andrady

2017). Secondary MPs are generated when plastic waste is exposed to UV light, heat and abrasion and is fragmented into smaller particles which can now accumulate across diverse organisms, including humans (Corradini et al. 2019, Medina Faull et al. 2024, Weber & Bigalke 2022, Huerta Lwanga et al. 2017, Alma et al. 2023, Curl et al. 2024, Bayo et al. 2021, Beriot et al. 2021, Kim et al. 2023, Lee et al. 2023). With their pervasive presence, MPs have become ubiquitous in the environment (Zolotova et al. 2022, Azeem et al. 2021), underscoring the urgent need for extensive research and effective management strategies to minimize their impact on ecosystems and human health. The primary pathways for human

exposure include inhalation, ingestion (such as seafood and processed foods), and use of cosmetics (containing microbeads) and textiles (releasing microfibers) (Matavos-Aramyan 2024, Thompson et al. 2024). While recent data shows an increase in MP exposure, comprehensive analysis of their accumulation, cellular and molecular effects, and health risks is still needed. Numerous studies have detected MPs in human samples, showing elimination from the body via urine or stool (Pironti et al. 2022, Hasanah et al. 2024, Braun et al. 2021, Liu et al. 2023a). Nevertheless, not all MPs are eliminated, some of them bioaccumulating in various tissues or organs (Jenner et al. 2022, Horvatits et al. 2022, Cetin et al. 2023, Guo et al. 2024, Amato-Lourenco et al. 2024, Zhao et al. 2023) and bodily fluids (Abbasi & Turner 2021, Huang et al. 2022, Sartorelli et al. 2020, Leslie et al. 2022, Ragusa et al. 2022b, Montano et al. 2023). In the female reproductive system, MPs were found in ovarian ectopic cysts and Fallopian tubes (Dong et al. 2024), endometrium (Sun et al. 2024a), amniotic fluid (Halfar et al. 2023), ovarian follicular fluid (Montano et al. 2024), umbilical cord blood (Sun et al. 2024b), and the placenta (Ragusa et al. 2021) (Supplementary Material - Figure S1).

Regarding the placenta, populational studies have been published in countries such as Italy (Ragusa et al. 2021), Germany (Braun et al. 2021), Czechia (Halfar et al. 2023), China (Liu et al. 2022, 2023b, Sun et al. 2024b), Iran (Amereh et al. 2022), USA (Weingrill et al. 2023, Garcia et al. 2024), and Canada (Zurub et al. 2024), where a correlation between the country, geographical factors, and the presence of MPs, including size and polymer types have been observed. However, there are no reports of MP accumulation in Brazil nor Latin-American pregnant women. Herein, we aimed to investigate the presence of MPs in placentas and umbilical cords from Brazilian pregnancies from

the State of Alagoas, providing the first evidence of MPs accumulation in such population.

MATERIALS AND METHODS

Sample collection

This pilot study is a cross-sectional, descriptive observational investigation focusing on term placentas and umbilical cords from the same participants. The study cohort comprised 10 participants blindly and randomly selected from a bigger study comprising 65 participants (average age: 26.7 ± 5.1 years; 38.3 ± 1.1 weeks of gestation). They were provided with informed consent terms and underwent either cesarean section or vaginal delivery. Ethical approval for research involving human subjects was obtained from the Ethics Committee (CAAE 58129422.3.0000.5013). Sampling was conducted at Hospital Universitário Professor Alberto Antunes (HUPAA) of the Federal University of Alagoas (UFAL) between June and October of 2023. Exclusion criteria included autoimmune and genetic conditions, as well as maternal age under 18 years old. All the procedures were performed using plastic-free protocols, as previously published by our group (Weingrill et al. 2023).

Collection and digestion of the samples

After delivery, placental and umbilical cord tissues were placed in glass containers with stainless steel lids before being transported to the research laboratory for processing. Each placental tissue sample was dissected from the amniochorionic membrane and the basal decidua, and weighed to achieve 50 g. Subsequently, the samples were thoroughly rinsed with glass-filtered Milli-Q water and immediately immersed in a lidded glass bottle containing glass-filtered 10% KOH solution (1:9; w/v), for one week at room temperature to ensure

complete digestion of all the organic tissue matter (Weingrill et al. 2023). After digestion, samples were filtered through glass fiber filters with 1.6 μm pores (Whatman GF/A, Sigma-Aldrich, St. Louis, MO, USA), washed with glass-filtered PBS and Milli-Q water to remove KOH, air dried, and stored in small metal containers for subsequent Micro-Raman spectroscopy analysis. For each batch of samples, different control (blank) filters were prepared: two exposed to Milli-Q and PBS used to rinse the samples, one exposed only to the KOH solution, and a dry control exposed to air and storage in the same conditions.

Analysis of microplastics by Micro-Raman spectroscopy

Filtered particles were first photographed by optical microscopy using a 100 x objective (Olympus IR, USA). Selected particles were then submitted to spectral acquisition using Raman spectroscopy (XploRA Raman spectrometer; a spectral range of 200–3200 cm^{-1} , 532 nm laser diode, 600 lines per mm grating, Horiba, Japan). To standardize the area to be analyzed, a 4 cm^2 square was used, and each particle's Raman spectra were acquired in 10 cycles of 5 seconds each. Finally, spectral analysis and particle characterization were conducted using the KnowItAll software (Wiley Science Solutions, Hoboken, NJ, USA), along with the SLOPP/SLOPPe free microplastic libraries.

Statistical Analysis

The results were tabulated, and data analysis was performed using GraphPad Prism (version 7.0; GraphPadSoftware, Inc. Boston, MA, USA). To determine the normal distribution of all data, the Shapiro–Wilk test was performed. Mann–Whitney test was used for MPs size comparison between organs. Paired t-test was used for the analysis of the concentration of MPs in 50 g of tissue. One-way ANOVA with Bonferroni was

performed to compare differences in polymer types and sizes. All the statistical analyses were performed with $p < 0.05$ considered statistically significant.

RESULTS

Demographics of pregnant women in Alagoas

Term placentas and umbilical cords were obtained from a cohort of 10 pregnant women, with overall characteristics described in Table I. All the participants are part of underrepresented minority communities and have clinical records of one or more pregnancies. The delivery methods included both vaginal and cesarean sections and fetal clinical data revealed an average birth weight of $3,210 \pm 0,642$ g (mean $\pm$ SEM), with no fetal malformations. All infants had APGAR scores ranging between 8 and 9 at both 1 and 5 minutes.

Microplastic Accumulation in placental and umbilical cord tissue

All the analyzed placenta ($n=10$) and umbilical cord ($n=10$) had microplastic particles detected, totaling 229 MPs particles. Of those, 110 were found in placental tissues, and 119 in umbilical cord tissues. MPs size in placental tissue was 11.98 ± 0.85 μm (mean $\pm$ SEM), with a range of 2.22 to 48.74 μm , while in umbilical cords, MPs size was 13.26 ± 0.8 μm (mean $\pm$ SEM), with a range of 1.64 to 52.6 μm (Figure 1a). No statistical differences have been found in MPs size comparing placentas and umbilical cords ($p = 0.0965$). Regarding the concentration in the tissues, we have not found statistical differences among the groups ($p = 0.0617$; Figure 1b), where placentas had 13.75 ± 1.44 MPs/50g of tissue, and umbilical cords had 26.67 ± 7.404 MPs/50g tissue. When analyzed individually, 8 out of 10 participants showed a higher concentration of MPs per 50 g in umbilical cord tissue compared to placental

Table I. Demographics and clinical data of pregnant women from Maceio, Brazil.

Sample number	Age (years)	Level of education	Gestational time (weeks and days)	Previous pregnancies (deliveries and abortions)	Delivery type	Maternal conditions and pregnancy complications	Maternal BMI	Fetal sex	Fetal weight (g)	Placental weight (g)	Estimation of the total amount of placental MPs (based on MPs/50 g tissue)
1	20	Elementary school	38w5d	2 (D2+A0)	Vaginal	Urinary tract infection	30	Female	3,430	783	293.62 MPs
2	28	Elementary school	40w1d	2 (D2+A0)	C-section	Urinary tract infection	25.5	Female	3,812	673	84.12 MPs
3	24	High school	38w6d	2 (D1+A0)	Vaginal	None	19.8	Male	2,850	427	138.77 MPs
4	30	Elementary school	39w	2 (D0+A2)	Vaginal	None	29	Male	3,120	616	231 MPs
5	21	Elementary school	39w2d	0 (D0+A0)	Vaginal	None	31.6	Female	3,236	533	159.9 MPs
6	28	Elementary school	38w	3 (D2+A1)	C-section	None	20.5	Male	2,538	309	100.42 MPs
7	25	Elementary school	38w	1 (D1+A0)	Vaginal	Urinary tract infection	28.9	Female	3,220	555	166.5 MPs
8	36	College education	34w4d	2 (D1+A1)	C-section	Gestational diabetes	37.9	Male	3,306	611	106.92 MPs
9	32	Elementary school	40w1d	1 (D1+A0)	C-section	Chronic arterial hypertension	31.6	Male	3,414	518	77.7 MPs
10	23	Elementary school	39w6d	2 (D2+A0)	Vaginal	Iron deficiency anemia	20.5	Female	3,260	698	209.4 MPs

tissue (Figure 1c). This finding raises a significant concern, indicating that MPs are likely crossing the placenta and reaching the developing fetus during pregnancy. Notably, of all control samples, only 13 MPs were detected in two air-exposed controls. These MPs were identified as polyvinyl sulfonic acid (PVSA), polyethylene co-propylene (PE-co-PP), polyamide (PA), polyethylene (PE), polyethylene vinyl acetate (PEVA), and polyurethane (PU). Importantly, most of these MPs did not match those identified in the corresponding analyzed samples, and those that did were excluded from further analysis. These findings suggest that the MPs observed in the controls likely originated from airborne sources during sample handling, emphasizing the importance of including controls, as even minimal MP contamination can result from air deposition despite strict plastic-free protocols.

Characterization of the microplastic polymer composition by Micro-Raman Spectroscopy

Microplastic particles had their polymer composition and associated chemicals characterized by Micro-Raman spectroscopy. In placental tissue, from the 110 MPs identified, polyethylene was the most frequent (29 PE-MPs; 26.36%), followed by polyurethane (19 PU-MPs; 17.27%), polyamide (17 PA-MPs; 15.45%), polyethylene vinyl acetate (13 PEVA-MPs; 11.82%), polypropylene (13 PP-MPs; 11.82%), and polystyrene (8 PS-MPs; 7.27%). Small frequencies were found for polyester (PES), polysulfone (PSU), and polyvinyl methyl ether (PVME), only in 2 MPs each (1.82%), while polycarbonate (PC), polymethyl methacrylate (PMMA), and mixtures of PS-co-polyvinyl chloride (PVC), PE with polyvinyl phosphate (PVP), and polypropylene

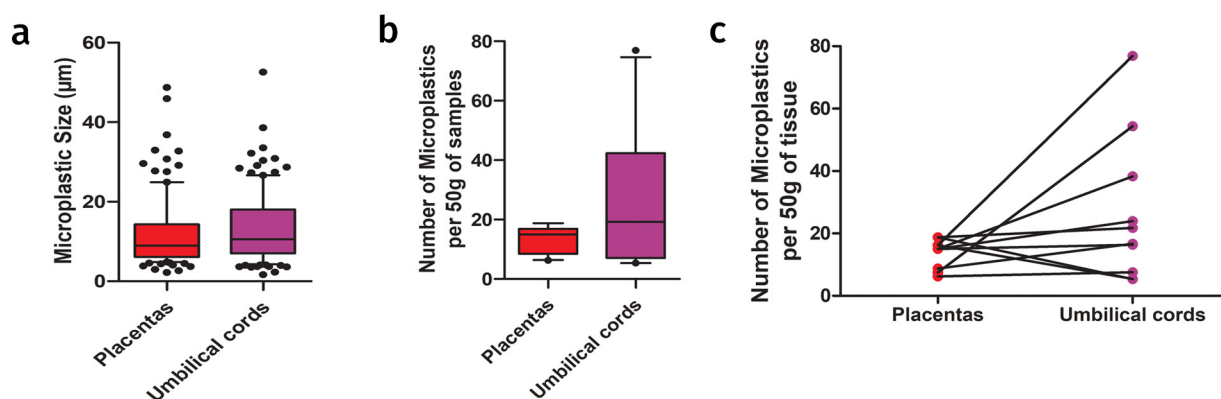


Figure 1. Size and concentration of MPs accumulated in placentas and umbilical cords. (a) Whisker-box plot showing the maximum length (µm) of the MPs from samples. Mann-Whitney test, mean $\pm$ SEM. (b) Number of MP particles in each of the 50 g of placenta or umbilical cord samples, Paired t test, mean $\pm$ SEM. (c) Correlation between the number of MPs in each of the samples from the same participants.

with polyethylene (PP with PE) were found only in 1 MP each (0.91%) (Figure 2a).

In addition, umbilical cord tissue had a similar polymer distribution when compared with the placental group, with small changes in their frequencies. Of the 119 MPs found in umbilical cords, the most frequent polymer remained the PE (37 MPs; 31.09%), followed by PA (30 MPs; 25.21%), PEVA (16 MPs; 13.44%), PP (10 MPs; 8.4%), PU (8 MPs; 6.72%), PES (6 MPs; 5.04%), and PP with PE mixtures (4 MPs; 3.36%). Lower frequencies were observed for PS, PE with PVP, and PC, with 2 MPs each (1.68%); and PSU, and PVC with 1 MP each (0.84%) (Figure 2a).

The next step was to analyze if there were differences regarding polymer types and MPs size, with no statistical changes being found ($p = 0.278$) (Figure 2b). Further analysis was performed to identify differences in MPs color and shape (Table SI). A higher prevalence of irregular MPs was observed in comparison to spherical MPs ($p < 0.001$, Figure 3a). No other morphologies were detected, and no changes were observed comparing the MP number of a particular morphology between placentas and umbilical cords (Figure 3a). Regarding MPs color, they were majorly transparent MPs (174; 76%), followed by white (23 MPs; 10.04%), brown, (10 MPs; 4.37%),

red (10 MPs; 4.37%), yellow (8 MPs; 3.5%), grey (7 MPs; 3.06%), black (2 MPs; 0.87%), and blue (1 MP; 0.44%) (Figure 3b). Nonetheless, it is important to highlight that several transparent MPs had a faint color or just a small colored part, but we characterized all of them as transparent since these colors were not as visible for us to identify without any doubt their true color. Also, some chemical additives were found to be associated with 84 of the MPs characterized (36.68%), with the most common being methyl formcel (11 MPs; 4.8%), and polymethacrylic acid (6 MPs; 2.62%), while others were found in less than 5 MPs (full list in Table SI). Additionally, the most frequent MPs found in our samples of placentas (PE, PA, and PU) and umbilical cords (PE, PEVA, and PA) are shown in photomicrography with their respective Raman spectra (Figure 4).

DISCUSSION

Microplastics are prevalent environmental pollutants, varying in size, polymer makeup, and cytotoxicity that may contain, absorb and transport harmful chemicals like bisphenols and phthalates (Osman et al. 2023). While recent reports have demonstrated the presence of MPs in placental tissue across various populations,

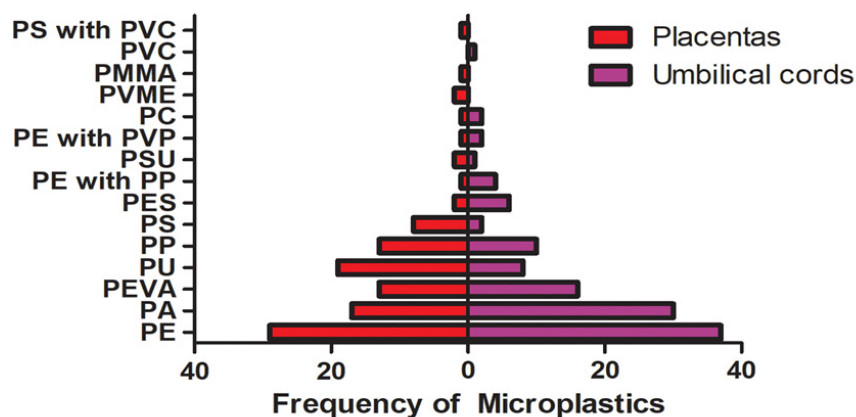
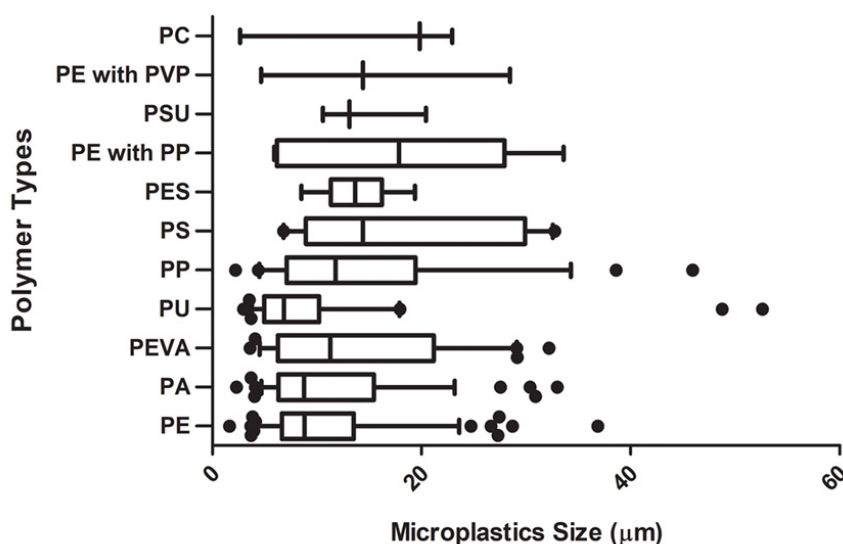
a**b**

Figure 2. Polymer identification by Micro-Raman spectroscopy. (a) Polymers frequency in placentas and umbilical cords: Polyethylene (PE), polyamide (PA), polyethylene vinyl acetate (PEVA), polyurethane (PU), polypropylene (PP), polystyrene (PS), polyester (PES), polyethylene-co-polypropylene (PE with PP); polysulfone (PSU); polyethylene and polyethylene and polyvinyl (PE with PVP); polycarbonate (PC), Polyvinyl Methyl Ether (PVME); Polymethyl Methacrylate (PMMA); polyvinyl chloride (PVC); Polystyrene-co-polyvinyl chloride (PS with PVC). **(b)** Polymers size comparison. One-way ANOVA with Bonferroni, mean $\pm$ SEM.

the present study is the first to report MP accumulation in placentas of pregnant women in Brazil. Additionally, our study is the first to match placental and umbilical cord tissues, investigating the ability of MPs to cross the placental barrier and accumulate in the umbilical cord. Although the small number of participants is a current limitation, several studies investigating the MPs accumulation in human tissues, had a similar or even lower number of participants (Braun et al. 2021, Weingrill et al. 2023, Ragusa et al. 2021, Garcia et al. 2024). This can be explained by the time-consuming and laborious process of identifying

MP particles by Micro-Raman spectroscopy. Nevertheless, Raman spectroscopy remains one of the most detailed techniques to characterize MPs polymer composition and their associated chemicals, supported by its high spatial resolution (down to 1.0 μm), extensive spectral coverage, sensitivity to non-polar functional groups, as well as being non-intrusive and requiring small sample amounts with minimal preparation (Araujo et al. 2018, Ribeiro-Claro et al. 2017, Mariano et al. 2021, Shim et al. 2017).

Moreover, the investigation of the levels of MPs accumulation in placentas and umbilical cords in Latin America are essential

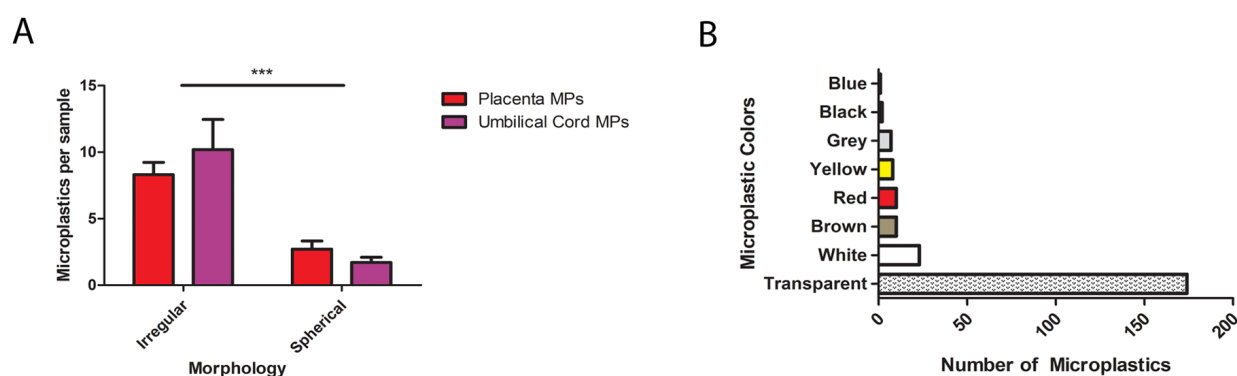


Figure 3. Microplastics shape and color. (A) Structural differences among MPs in placentas and umbilical cords show a higher number of irregular MPs in comparison to spherical MPs, Two-way ANOVA with Bonferroni, mean $\pm$ SEM, $p < 0.001$. (B) Frequency of colored MPs.

to understand the regional contamination of its countries, such as Brazil. Brazil has vast coastal areas, agricultural areas, the continued development of industrial parks, and the lack of appropriate waste management, which could be potential risks to MPs contamination (Oceana 2024). Published studies on placental MPs were produced in socio-demographically distinct populations, with different diet habits and exposure levels to pollutants, although all localized in the North Hemisphere (Weingrill et al. 2023, Garcia et al. 2024, Zurub et al. 2024, Ragusa et al. 2022a, Amereh et al. 2022, Halfar et al. 2023, Braun et al. 2021, Liu et al. 2023a, Zhu et al. 2023, Sun et al. 2024b, Zuri et al. 2023). As such, we have assessed the MP accumulation in ten pregnant women from Maceio, the capital of the Alagoas state in Brazil, which has a lower human development index (HDI), and a significant amount of underrepresented minority communities. Localized near the Equator line, on the Northeast Atlantic coast of Brazil, Maceio has a rich seafarer culture, where fish, mussels, and crabs, are commonly consumed by the population (Santos et al. 2023). Maceio struggles with environmental pollution, as 75% of the waste found in coastal areas is of plastic origin (Andrades et al. 2020). Environmental studies have also detected concerning levels of heavy

metal pollution in local waters and farmed mussels, with similar concentrations found in the blood of nearby residents (Santos et al. 2021). A study of dietary habits in Maceio showed significantly higher consumption of ultra-processed foods compared to natural products (Almeida et al. 2024). This trend has population health implications, as ultra-processed foods are often faster, cheaper, and more accessible to underrepresented communities (de Medeiros et al. 2024). Interestingly, packaging from ultra-processed foods was the most common waste type found in a large-scale study of plastic waste along Brazil's coasts (Andrades et al. 2020). Furthermore, due to insufficiently treated tap water, many residents rely on bottled water, often transported on bikes, motorcycles, or open trucks. This exposes the containers to intense UV radiation, which accelerates the release of MPs and chemical additives into the water (Hou et al. 2021).

These factors likely contribute to the high levels of MP exposure among Maceio's population, as reflected in our findings: all examined placentas and umbilical cords contained significant amounts of MPs. In Hawai'i, USA, 60% of placentas sampled in 2006 contained MPs, whereas 100% of those sampled in 2021 did, highlighting the increase in placental

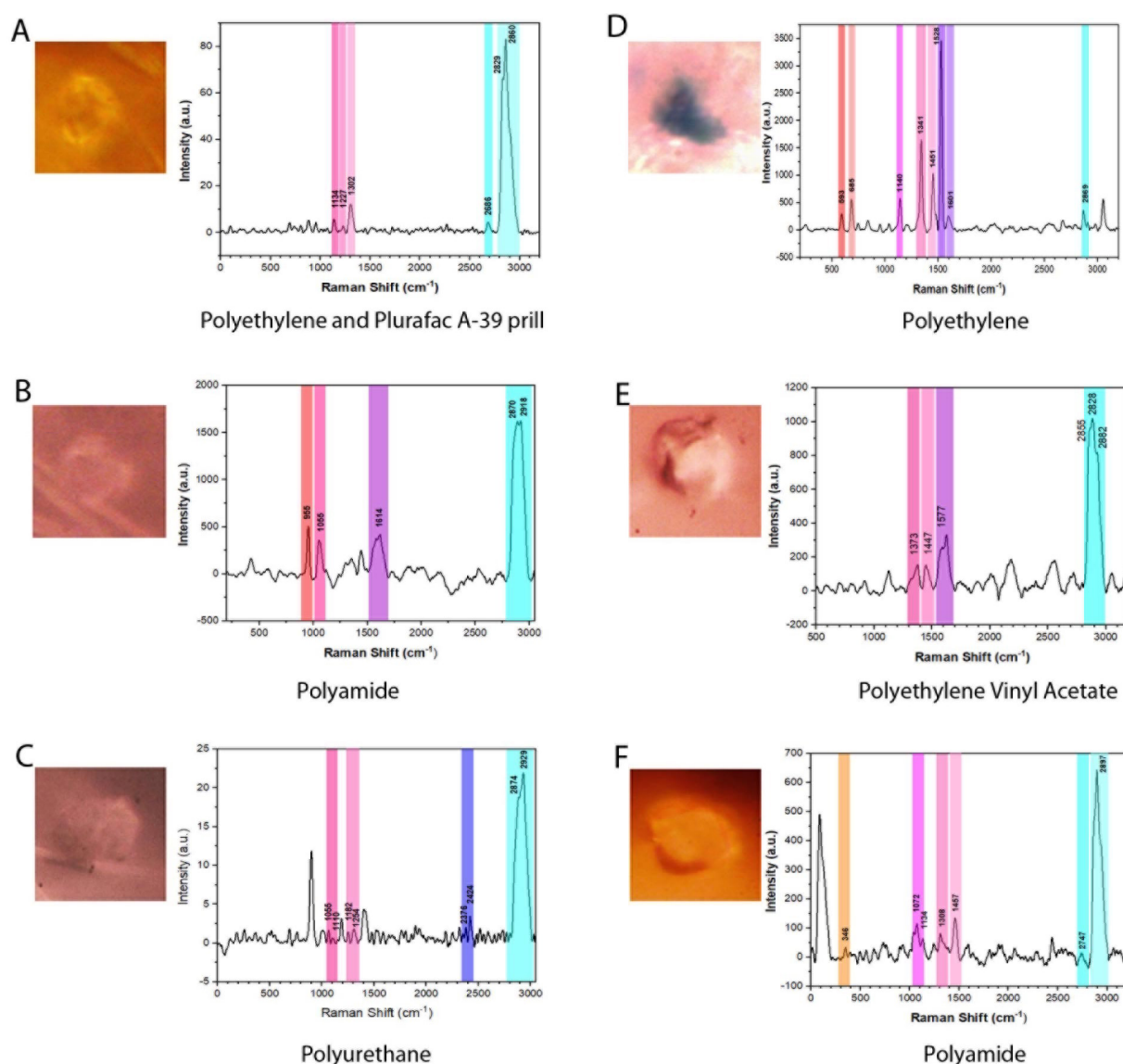


Figure 4. Micro-Raman Spectral analysis of selected MPs from placentas and umbilical cords (A) Polyethylene with Plurafac- A-39 Prill (9th MP from the placenta of participant number 3). (B) Polyamide (4th MP from the placenta of participant number 8). (C) Polyurethane (9th MP from the placenta of participant number 1). (D) Polyethylene (19th MP from the umbilical cord of participant number 9). (E) Polyethylene vinyl acetate (5th MP from the umbilical cord of participant number 6). (F) Polyamide (3rd MP from the umbilical cord of participant number 2). All photomicrographs were acquired at 100 × objective (Olympus PlanFL N 100x/0.95).

exposure alongside rising global plastic production and pollution (Weingrill et al. 2023, Thompson et al. 2024). Among the 2021 samples from Hawai'i, MP particle sizes ranged from 1 to 44 μm , with an average size of 5.14 μm (Weingrill et al. 2023), comparable to an Italian study reporting MPs between 5 and 10 μm (Ragusa et

al. 2021, Amereh et al. 2022). Other research has identified larger MPs, between 20 and 50 μm (Halfar et al. 2023, Liu et al. 2023a, b), with some studies detecting MPs over 50 μm (Braun et al. 2021, Zurub et al. 2024, Zhu et al. 2023, Halfar et al. 2023). It is essential to interpret these comparisons cautiously, as different methods

were employed to characterize and measure MPs, and no standardized methodology currently exists. Regarding concentration, we observed an average of 13.75 MPs per 50 g of placental tissue and 26.67 MPs per 50 g of umbilical cord tissue. While umbilical cord data cannot be compared to other studies due to the novelty of this finding, the detection of MPs in umbilical cord tissue provides new insights and complements existing evidence of MP presence in amniotic fluid and meconium (Liu et al. 2023a, Braun et al. 2021, Halfar et al. 2023). This information strengthens the hypothesis that fetuses are exposed to MPs and associated chemicals during pregnancy.

In terms of MPs concentration in placental tissue, several data points allow for comparison. This report found a similar concentration of MPs in placentas from Maceió's population compared to placentas collected in 2021 from a Hawaiian cohort (Weingrill et al. 2023), aligning with studies reporting concentrations between 0 and 18 MPs/g of placenta (Ragusa et al. 2021, Liu et al. 2023a, Zhu et al. 2023). Only one study has reported an average of 126.8 µg of MPs per gram of placenta (Garcia et al. 2024), which utilized a different analytical method and sample processing approach. The analysis of MP polymer composition revealed a wide range of polymers, with polyethylene (PE) being the most abundant in both placentas and umbilical cords. This finding is consistent with studies worldwide that also report high levels of PE in several tissues, including placenta (Amereh et al. 2022, Braun et al. 2021, Ragusa et al. 2022a, Amato-Lourenco et al. 2024, Roslan et al. 2024). The high concentrations of PE, commonly used in packaging materials, plastic bags, and films, highlights the urgent need for regulations on its use, improved waste management, and alternative materials. In addition to PE, we frequently identified PA, PEVA, and PU in both organs. These polymers are also widely reported

in existing placental studies (Sun et al. 2024b, Weingrill et al. 2023, Garcia et al. 2024, Liu et al. 2023a, b), with PA mainly used in textiles and industrial membrane filters (Lara et al. 2021), PEVA in laundry products and textiles (Rolsky & Kelkar 2021), and PU in foams, adhesives, and textiles (Akindoyo et al. 2016, Kemona & Piotrowska 2020). Interestingly, these polymers also known to be primary sources of MPs in fresh and ocean waters (Galafassi et al. 2019). Noteworthy, other polymers such as PP, PES, PVC, PET, and PS also appear as prevalent MPs in different populations (Weingrill et al. 2023, Garcia et al. 2024, Amereh et al. 2022, Ragusa et al. 2021, Braun et al. 2021, Halfar et al. 2023).

Umbilical cord information is scarcer, as only one other study has analyzed this tissue. Sun et al. (2024b) showed the presence of MPs in ten from twelve samples of umbilical cords, where these tissues presented the higher concentration of MPs/g of tissue in comparison to umbilical cord vein blood, placenta, amniochorionic membrane, amniotic fluid, and maternal blood. Regarding polymers, they were mostly PA, followed by far from PU and acrylates, while PE contamination was rather small (Sun et al. 2024b).

Such differences in polymers frequency could represent a reflection of the local geo-demographics and environmental exposure to these pollutants that are differentially accumulating across each population. Alongside the polymers, we detected several chemical compounds commonly linked to polymer production, although most of them were restricted to only few MPs. Moreover, we have a limitation on characterizing such chemical products due to weathering, and lack of available libraries. Overcome such limitation is important in the field, as Groh et al. (2019), identified over 4,000 potentially harmful chemicals associated with plastic packaging alone with these numbers

growing faster than toxicity studies can keep pace.

Furthermore, our results add to other studies on umbilical cords, amniotic fluid and membranes, and meconium, to indicate that MPs are probably passing through the placental barrier somehow, indicating fetal bioaccumulation. In the placenta, endocytosis of nanoplastics is not new. Grafmueller et al. (2015) described in an *ex vivo* human placental perfusion model the bidirectional transfer of such particles up to 300 nm, which tended to accumulate inside the syncytiotrophoblast but also translocated from maternal to fetal size and *vice versa*. Although nanoplastics are in the nano size, MPs up to 10 µm were recently shown to be internalized by Bewo cells (Dusza et al. 2023). Ragusa et al. (2022a) also showed MP-like particles ranging from 2.1 to 18.5 µm inside placental chorionic villi. The MP-like particles had morphology (irregularity in the shapes, borders, and surfaces) and chemical composition (appearance as compact carbon microparticles) comparable to those of the MPs. Nevertheless, despite the growing evidence on MPs internalization in placenta and several organs, the mechanistic involved in such internalization is still unveiled.

CONCLUSIONS

This study highlights a concerning accumulation of MPs in placentas from a vulnerable and underrepresented population cohort in Alagoas, Brazil. As the first study of its kind conducted in Latin America, these findings underscore the urgent need for further comparative research across diverse populations within this vulnerable region. Importantly, our results strengthen the hypothesis that MPs can cross the placental barrier, suggesting fetal exposure to both polymer particles and associated

chemical additives during critical stages of in utero development. Although the precise health implications of such early-life exposure remain unclear, the detection of MPs in both placental and umbilical cord tissues raises significant concerns about potential risks to fetal health and subsequent developmental outcomes. Given the growing body of evidence from *in vitro* and *in vivo* studies linking MP exposure to health risks, our findings emphasize the necessity of urgent investigation into the long-term maternal and fetal health consequences of prenatal MP exposure, as well as developmental outcomes following birth. This research is particularly crucial for communities of lower socioeconomic status, who may face greater environmental exposure and thus higher potential health risks.

Acknowledgments

The authors thank the HUPAA-UFAL clinicians that helped with patient's data and recruitment, and Juliane Silva for technical support in the Cell Biology Laboratory. The authors are grateful to the Fundação de Amparo à Pesquisa do Estado de Alagoas (FAPEAL) (SOP, PDCTR 05/2022 and AUB, APQ 02/2022) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (AUB, 443526/2023-0 and 403355/2023-0) for financial support. JU was supported by the National Institute of General Medical Sciences of the National Institutes of Health under award number 3P30GM131944-05S1.

REFERENCES

- ABBASI S & TURNER A. 2021. Human exposure to microplastics: A study in Iran. *J Hazard Mat* 403: 123799.
- AKINDOYO JO, BEG MDH, GHAZALI S, ISLAM MR, JEYARATNAM N & YUVARAJ AR. 2016. Polyurethane types, synthesis and applications – a review. *RSC Advances* 6: 114453-114482.
- ALMA AM, DE GROOT GS & BUTELER M. 2023. Microplastics incorporated by honeybees from food are transferred to honey, wax and larvae. *Environ Pollut* 320: 121078.
- ALMEIDA KB, LOPES TE, EMERY TS, BEZERRA AR, FRAGOSO MBT & OLIVEIRA ACMD. 2024. Associação entre a contribuição energética de alimentos de acordo com a classificação

nova e o estado nutricional de gestantes atendidas pela rede pública de maceió, alagoas. *Gep News* 8: 8-14.

AMATO-LOURENCO LF ET AL. 2024. Microplastics in the Olfactory Bulb of the Human Brain. *JAMA network open* 7: e2440018.

AMEREH F, AMJADI N, MOHSENI-BANDPEI A, ISAZADEH S, MEHRABI Y, ESLAMI A, NAEIJI Z & RAFIEE M. 2022. Placental plastics in young women from general population correlate with reduced foetal growth in IUGR pregnancies. *Environ Pollut* 314: 120174.

ANDRADES R ET AL. 2020. Anthropogenic litter on Brazilian beaches: Baseline, trends and recommendations for future approaches. *Mar. Pollut. Bull* 151: 110842.

ANDRADY AL. 2017. The plastic in microplastics: A review. *Mar Pollut Bull* 119: 12-22.

ARAUJO CF, NOLASCO MM, RIBEIRO AMP & RIBEIRO-CLARO PJA. 2018. Identification of microplastics using Raman spectroscopy: Latest developments and future prospects. *Water Res* 142: 426-440.

AZEEM I ET AL. 2021. Uptake and Accumulation of Nano/ Microplastics in Plants: A Critical Review. *J Nanomater* 11.

BAYO J, OLMOS S & LÓPEZ-CASTELLANOS J 2021. Assessment of Microplastics in a Municipal Wastewater Treatment Plant with Tertiary Treatment: Removal Efficiencies and Loading per Day into the Environment. *Water* 13: 1339.

BERIOT N, PEEK J, ZORNOZA R, GEISSEN V & HUERTA LWANGA E. 2021. Low density-microplastics detected in sheep faeces and soil: A case study from the intensive vegetable farming in Southeast Spain. *Sci Total Environ* 755: 142653.

BRAUN T, EHRLICH L, HENRICH W, KOEPEL S, LOMAKO I, SCHWABL P & LIEBMANN B. 2021. Detection of Microplastic in Human Placenta and Meconium in a Clinical Setting. *Pharm J* 13.

CETIN M, DEMIRKAYA MILOGLU F, KILIC BAYGUTALP N, CEYLAN O, YILDIRIM S, ESER G & GUL Hİ. 2023. Higher number of microplastics in tumoral colon tissues from patients with colorectal adenocarcinoma. *Environ Chem Lett* 21: 639-646.

CORRADINI F, BARTHOLOMEUS H, HUERTA LWANGA E, GERTSEN H & GEISSEN V. 2019. Predicting soil microplastic concentration using vis-NIR spectroscopy. *Sci Total Environ* 650: 922-932.

CROXATTO VEGA G, GROSS A & BIRKVED M. 2021. The impacts of plastic products on air pollution - A simulation study for advanced life cycle inventories of plastics covering secondary microplastic production. *Sustain Prod Consum* 28: 848-865.

CURL LF, HURST SA, POMORY CM, LAMONT MM & JANOSIK AM. 2024. Assessing microplastics contamination in unviable loggerhead sea turtle eggs. *Sci Total Environ* 912: 169434.

DE MEDEIROS JM, SILVA-NETO LGR, DOS SANTOS TLF, DOS SANTOS NETO JE & DE MENEZES TOLEDO FLORENCIO TM. 2024. Higher consumption of ultra-processed foods is associated with obesity and abdominal obesity in socially vulnerable Brazilian women. *Nutr Bull* 49: 199-208.

DONG C, XU H, LIN Y, ZHANG B, YU Z, XIE Y, YU J & MA D. 2024. Microplastics detected in three types of female reproductive organs using micro-Raman spectroscopy. *Ecotoxicol Environ Saf* 285: 117099.

DUSZA HM, KATRUKHA EA, NIJMEIJER SM, AKHMANOVA A, VETHAAK AD, WALKER DI & LEGLER J. 2023. Uptake, Transport, and Toxicity of Pristine and Weathered Micro- and Nanoplastics in Human Placenta Cells. *Environ Health Perspect* 130: 97006.

EUROPE. 2023. Plastics – the Facts 2023: An analysis of European plastics production, demand and waste data. <https://plasticseurope.org/knowledge-hub/plastics-the-fast-facts-2023/>.

GALAFASSI S, NIZZETTO L & VOLTA P. 2019. Plastic sources: A survey across scientific and grey literature for their inventory and relative contribution to microplastics pollution in natural environments, with an emphasis on surface water. *Sci Total Environ* 693: 133499.

GARCIA MA ET AL. 2024. Quantitation and identification of microplastics accumulation in human placental specimens using pyrolysis gas chromatography mass spectrometry. *Toxicol Sci* 199: 81-88.

GRAFMUELLER S ET AL. 2015. Transfer studies of polystyrene nanoparticles in the ex vivo human placenta perfusion model: key sources of artifacts. *Sci Technol Adv Mater* 16: 044602.

GROH KJ ET AL. 2019. Overview of known plastic packaging-associated chemicals and their hazards. *Sci Total Environ* 651: 3253-3268.

GUO X ET AL. 2024. Discovery and analysis of microplastics in human bone marrow. *J Hazard Mater* 477: 135266.

HALFAR J, CABANOVA K, VAVRA K, DELONGOVA P, MOTYKA O, SPACEK R, KUKUTSCHOVA J, SIMETKA O & HEVIANKOVA S. 2023. Microplastics and additives in patients with preterm birth: The first evidence of their presence in both human amniotic fluid and placenta. *Chemosphere* 343: 140301.

HASANAH U, AMQAM H, SEPTAMI AE, CHALID M & ARIS AZ. 2024. Plasticizing Pregnancy: Microplastics Identified in Expectant Mothers' Feces. *Environ health insights*. 18: 11786302241235810.

- HORVATITST, TAMMINGAM, LIU B, SEBODEM, CARAMBIAA, FISCHER L, PUSCHEL K, HUBER S & FISCHER EK. 2022. Microplastics detected in cirrhotic liver tissue. *EBioMedicine* 82: 104147.
- HOU L, KUMAR D, YOO CG, GITSOV I & MAJUMDER ELW. 2021. Conversion and removal strategies for microplastics in wastewater treatment plants and landfills. *Chem Eng J* 406: 126715.
- HUANG S ET AL. 2022. Detection and Analysis of Microplastics in Human Sputum. *Environ Sci Techno* 56: 2476-2486.
- HUERTA LWANGA E ET AL. 2017. Field evidence for transfer of plastic debris along a terrestrial food chain. *Sci Rep* 7: 14071.
- JENNER LC, ROTCHELL JM, BENNETT RT, COWEN M, TENTZERIS V & SADOFSKY LR. 2022. Detection of microplastics in human lung tissue using muFTIR spectroscopy. *Sci Total Environ* 831: 154907.
- KEMONA A & PIOTROWSKA M. 2020. Polyurethane Recycling and Disposal: Methods and Prospects. *Polymers* 12: 1752.
- KIM Y, KIM H, JEONG MS, KIM D, KIM J, JUNG J, SEO HM, HAN HJ, LEE WS & CHOI CY. 2023. Microplastics in gastrointestinal tracts of gentoo penguin (*Pygoscelis papua*) chicks on King George Island, Antarctica. *Sci Rep* 13: 13016.
- LARA LZ, BERTOLDI C, ALVES NM & FERNANDES AN. 2021. Sorption of endocrine disrupting compounds onto polyamide microplastics under different environmental conditions: Behaviour and mechanism. *Sci Total Environ* 796: 148983.
- LEE Y, CHO J, SOHN J & KIM C. 2023. Health Effects of Microplastic Exposures: Current Issues and Perspectives in South Korea. *Yonsei Med J* 64: 301-308.
- LESLIE HA, VAN VELZEN MJM, BRANDSMA SH, VETHAAK AD, GARCIA-VALLEJO JJ & LAMOREE MH. 2022. Discovery and quantification of plastic particle pollution in human blood. *Environ Int* 163: 107199.
- LIU S, GUO J, LIU X, YANG R, WANG H, SUN Y, CHEN B & DONG R. 2023a. Detection of various microplastics in placentas, meconium, infant feces, breastmilk and infant formula: A pilot prospective study. *Sci Total Environ* 854: 158699.
- LIU S, LIU X, GUO J, YANG R, WANG H, SUN Y, CHEN B & DONG R. 2023b. The Association Between Microplastics and Microbiota in Placentas and Meconium: The First Evidence in Humans. *Environ Sci Techno* 57: 17774-17785.
- LIU Z, ZHUAN Q, ZHANG L, MENG L, FU X & HOU Y. 2022. Polystyrene microplastics induced female reproductive toxicity in mice. *J Hazard Mater* 424: 127629.
- MARIANO S, TACCONI S, FIDALEO M, ROSSI M & DINI L. 2021. Micro and Nanoplastics Identification: Classic Methods and Innovative Detection Techniques. *Front Toxicol* 3: 636640.
- MATAVOS-ARAMYAN S. 2024. Addressing the microplastic crisis: A multifaceted approach to removal and regulation. *Environ Adv* 17: 100579.
- MEDINA FAULL LE, ZALIZNYAK T & TAYLOR GT. 2024. From the Caribbean to the Arctic, the most abundant microplastic particles in the ocean have escaped detection. *Mar Pollut Bull* 202: 116338.
- MONTANO L ET AL. 2024. First evidence of microplastics in human ovarian follicular fluid: an emerging threat to female fertility. *medRxiv*: 2024.2004.2004.24305264.
- MONTANO L, GIORGINI E, NOTARSTEFANO V, NOTARI T, RICCIARDI M, PISCOPO M & MOTTA O. 2023. Raman Microspectroscopy evidence of microplastics in human semen. *Sci Total Environ* 901: 165922.
- OCEANA. 2024. Fragments of destruction: impact of plastic on Brazilian marine biodiversity. Brasília. DF.: Organization Iran Magno. 1st edition.
- OSMAN AI ET AL. 2023. Microplastic sources, formation, toxicity and remediation: a review. *Environ Chem Lett* 21: 2129-2169.
- PIRONTI C, NOTARSTEFANO V, RICCIARDI M, MOTTA O, GIORGINI E & MONTANO L. 2022. First Evidence of Microplastics in Human Urine, a Preliminary Study of Intake in the Human Body. *Toxics* 11(1): 40. doi: 10.3390/toxics11010040.
- RAGUSA A ET AL. 2022a. Deeply in Plasticenta: Presence of Microplastics in the Intracellular Compartment of Human Placentas. *Int J Environ Res Public Health* 19: 11593.
- RAGUSA A ET AL. 2022b. Raman Microspectroscopy Detection and Characterisation of Microplastics in Human Breastmilk. *Polymers* 14(13): 2700. <https://doi.org/10.3390/polym14132700>.
- RAGUSA A ET AL. 2021. Plasticenta: First evidence of microplastics in human placenta. *Environ Int* 146: 106274.
- RIBEIRO-CLARO P, NOLASCO MM & ARAÚJO C 2017. Chapter 5 - Characterization of Microplastics by Raman Spectroscopy. In: Rocha-Santos TAP & Duarte AC (Eds), *Comprehensive Analytical Chemistry*: Elsevier, p. 119-151.
- ROLSKY C & KELKAR V. 2021. Degradation of Polyvinyl Alcohol in US Wastewater Treatment Plants and Subsequent Nationwide Emission Estimate. *Int J Environ Res Public Health* 18.

ROSLAN NS, LEE YY, IBRAHIM YS, TUAN ANUAR S, YUSOF K, LAI LA & BRENTNALL T. 2024. Detection of microplastics in human tissues and organs: A scoping review. *J glob health* 14: 04179.

SANTOS CC, GOMES EP, MAIA CFS & MAIA SMF. 2023. Wastewater management in the state of Alagoas, Brazil: greenhouse gas emissions and organic load removal efficiency of wastewater treatment plants. *Gaia* 17: 37-56.

SANTOS MCD, SILVA FILHO RCD, LEITE ACR, BOTERO WG, SANTOS JCC & NASCENTES CC. 2021. Evaluation of potentially toxic elements in Mundaú Lagoon (Maceió, AL-Brazil): systematic environmental monitoring of water and food quality. *J Braz Chem Soc (Online)* 32: 1762-1772.

SARTORELLI P, INDINI S, BIANCHI F, D'ALESSANDRO M, BERGANTINI L, CAMELI P, MAZZEI MA, SCANCARELLO G, BARABESI L & BARGAGLI E. 2020. Cytological analysis of bronchoalveolar lavage fluid in asbestos-exposed workers. *Med Lav* 111: 379-387.

SHIM WJ, HONG SH & EO SE. 2017. Identification methods in microplastic analysis: a review. *Anal Methods* 9: 1384-1391.

SUN H, SU X, MAO J, LIU Y, LI G & DU Q. 2024b. Microplastics in maternal blood, fetal appendages, and umbilical vein blood. *Ecotoxicol Environ Saf* 287: 117300.

SUN J, SUI M, WANG T, TENG X, SUN J & CHEN M. 2024a. Detection and quantification of various microplastics in human endometrium based on laser direct infrared spectroscopy. *Sci Total Environ* 906: 167760.

THOMPSON RC, COURTENE-JONES W, BOUCHER J, PAHL S, RAUBENHEIMER K & KOELMANS AA. 2024. Twenty years of microplastic pollution research-what have we learned? *Science* 386: eadl2746.

WEBER CJ & BIGALKE M. 2022. Opening Space for Plastics—Why Spatial, Soil and Land Use Data Are Important to Understand Global Soil (Micro)Plastic Pollution. *Microplastics*: 610-625.

WEINGRILL RB ET AL. 2023. Temporal trends in microplastic accumulation in placentas from pregnancies in Hawai'i. *Environ Int* 180: 108220.

ZHAO Q, ZHU L, WENG J, JIN Z, CAO Y, JIANG H & ZHANG Z. 2023. Detection and characterization of microplastics in the human testis and semen. *Sci Total Environ* 877: 162713.

ZHU L, ZHU J, ZUO R, XU Q, QIAN Y & AN L. 2023. Identification of microplastics in human placenta using laser direct infrared spectroscopy. *Sci Total Environ* 856: 159060.

ZOLOTOVA N, KOSYREVA A, DZHALILOVA D, FOKICHEV N & MAKAROVA O. 2022. Harmful effects of the microplastic

pollution on animal health: a literature review. *PeerJ* 10: e13503.

ZURI G, KARANASIOU A & LACORTE S. 2023. Microplastics: Human exposure assessment through air, water, and food. *Environ Int* 179: 108150.

ZURUB R, BAINBRIDGE S, RAHMAN L, HALAPPANAVAR S & WADE MG. 2024. Particulate Contamination of Human Placenta: Plastic and non-plastic. *bioRxiv*: 2024.2003.2001.583005.

SUPPLEMENTARY MATERIAL

Figure S1.

Table S1.

How to cite

OLIVEIRA CWL, OLIVEIRA LFA, GARCIA J, WEINGRILL RB, URSCHITZ J, SOUZA ST, FONSECA EJS, OSPINA-PRIETO S & BORBELY AU. 2025. First evidence of microplastic accumulation in placentas and umbilical cords from pregnancies in Brazil. *An Acad Bras Cienc* 97: e20241298. DOI 10.1590/0001-3765202520241298.

*Manuscript received on November 7, 2024;
accepted for publication on May 4, 2025.*

CAMILA WANDERLEY L. OLIVEIRA¹

<https://orcid.org/0000-0001-9223-7344>

LAIS F.A.M. OLIVEIRA²

<http://orcid.org/0000-0003-4915-1750>

JACOB GARCIA³

<https://orcid.org/0000-0002-8563-0970>

RODRIGO B. WEINGRILL⁴

<https://orcid.org/0000-0003-3699-4388>

JOHANN URSCHITZ⁴

<https://orcid.org/0000-0002-8894-5716>

SAMUEL T. SOUZA²

<https://orcid.org/0000-0003-0151-118X>

EDUARDO JORGE S. FONSECA²

<http://orcid.org/0000-0001-5975-2467>

STEPHANIE OSPINA-PRIETO¹

<https://orcid.org/0000-0002-1744-6354>

ALEXANDRE U. BORBELY¹

<https://orcid.org/0000-0001-6737-0901>

¹Federal University of Alagoas, Cell Biology Laboratory, Institute of Biological and Health Sciences, Campus A.C. Simões. Av. Lourival Melo Mota, 57072-900 Maceió, AL, Brazil

²Federal University of Alagoas, Group of Optics and Nanoscopy, Physics Institute, Campus A.C. Simões. Av. Lourival Melo Mota, 57072-900 Maceió, AL, Brazil

³University of Hawai'i at Manoa, Department of Obstetrics and Gynecology, John A. Burns School of Medicine, 1319 Punahou Street, 96826 Honolulu, HI, USA

⁴University of Hawai'i at Manoa, Institute for Biogenesis Research, Department of Anatomy, Biochemistry, and Physiology, John A. Burns School of Medicine, 651 Ilalo Street, BSB 110A, 96813 Honolulu, HI, USA

Correspondence to: **Alexandre Urban Borbely**
E-mail: alexandre.borbely@icbs.ufal.br

Authors Contributions

Alexandre U. Borbely: Conceptualization; Data curation; Funding acquisition; Project administration; Resources; Supervision; Validation; Roles/Writing - original draft; Writing - review & editing. Camila Wanderley L. Oliveira: Formal analysis; Investigation; Methodology; RBW; Roles/Writing - original draft. Stephanie Ospina-Prieto: Formal analysis; Investigation; Methodology; Project administration; Supervision; Roles/Writing - original draft; Writing - review & editing. Rodrigo B. Weingrill: Formal analysis; Funding acquisition; Methodology; Resources; Validation; Roles/Writing - original draft. Johann Urschitz: Funding acquisition; Resources; Writing - review & editing. Lais F. A. M. Oliveira: Methodology. Samuel T. Souza: Supervision; Validation. Eduardo Jorge S. Fonseca: Supervision; Validation. Jacob Garcia: Writing - review & editing.

