First report on the presence of microplastics in chicken livers and gizzards in Costa Rica

Primer reporte de la presencia de microplásticos en hígados y mollejas de pollos de Costa Rica

Natalia Soto-Barrientos[1], Catalina Víquez-Murillo[2], Karol Ulate-Naranjo[3], Natalia Hernández-Montero[4], Andrea García-Rojas[3*]

[1]Clínica de Especies Mayores, Escuela de Medicina Veterinaria, Universidad Nacional, Heredia, Costa Rica. natalia.soto.barrientos@una.ac.cr, ORCID: https://orcid.org/0000-0002-1540-0563

[2]Laboratorio de Histología, Escuela de Medicina Veterinaria, Universidad Nacional, Heredia, Costa Rica. catalina.viquez.murillo@una.ac.cr, ORCID: https://orcid.org/0000-0002-3957-2992

[3]Laboratorio de Estudios Marino Costeros, Escuela de Ciencias Biológicas, Universidad Nacional, Heredia, Costa Rica. karol.ulate.naranjo@una.ac.cr, ORCID: https://orcid.org/0000-0001-5687-555X; andrea.garcia.rojas@una.ac.cr, ORCID: https://orcid.org/0000-0003-3451-7094

[4]Centro de Investigación en Ciencia e Ingeniería de Materiales (CICIMA), Escuela de Ingeniería Química, Universidad de Costa Rica, San José, Costa Rica. natalia.hernandezmontero@ucr.ac.cr, ORCID: https://orcid.org/0000-0001-5474-5073

*Correspondence Author: Andrea García-Rojas (andrea.garcia.rojas@una.ac.cr)

Abstract

Microplastic (MP) pollution is a global environmental issue affecting marine and terrestrial ecosystems. In Costa Rica, concern is growing, with recent findings in marine environment, cattle and pig livers. This study quantified and characterized MPs in chicken livers and gizzards intended for human consumption. Samples were collected from local butcher shops, digested chemically, and analyzed by microscopy and Fourier-transform infrared spectroscopy (FTIR). MPs were detected in 82.80% (n = 77) of 93 livers and 86.84% (n = 99) of 114 gizzards, predominantly as translucent and blue fibers. Several polymers, including polypropylene, polyesters, nylon, PMMA, and PVC, were identified, though differentiation from natural cellulose fibers remained challenging. The widespread presence of MPs in poultry offal highlights potential risks to food safety and environmental health, emphasizing the need for improved analytical methods, contamination control in production chains, and further research to assess health impacts.

Keywords: microplastics, poultry, chicken, food safety, FTIR

Resumen

La contaminación por microplásticos (MP) es un problema ambiental global que afecta a ecosistemas marinos y terrestres. En Costa Rica la preocupación crece, con hallazgos recientes en ecosistemas marinos, hígados de bovinos y cerdos. Este estudio cuantificó y caracterizó MPs en hígados y mollejas de pollo destinados al consumo humano. Las muestras se obtuvieron en carnicerías locales, se sometieron a digestión química y se analizaron mediante microscopía y espectroscopía infrarroja por transformada de Fourier (FTIR). Se detectaron MPs en el 82,80 % (n = 77) de 93 hígados y en el 86,84 % (n = 99) de 114 mollejas, predominando fibras translúcidas y azules. Se identificaron diversos polímeros, entre ellos polipropileno, poliésteres, nailon, PMMA y PVC; sin embargo, la diferenciación entre fibras sintéticas y celulosa natural presentó dificultades. La amplia presencia de MPs en vísceras de pollo plantea riesgos potenciales para la inocuidad alimentaria y la salud ambiental, lo que resalta la necesidad de métodos analíticos más precisos, un mayor control de la contaminación en la cadena productiva y más investigaciones sobre su impacto en la salud.

Palabras clave: microplásticos, aves de corral, pollo, seguridad alimentaria, FTIR

Introduction

Microplastic (MP) contamination is a significant global environmental problem, affecting ecosystems from deep marine environments to polar regions and coastlines on every continent (Blumenröder et al., 2017; Cox et al., 2019; Blettler et al., 2018; Dris et al., 2018; Horton et al., 2017; Ramachandraiah et al., 2022). This pollution also impacts freshwater and terrestrial systems, and MPs can even be transported through atmospheric condensation and deposited as rain in remote areas (Allen et al., 2019).

Although MPs in marine organisms are increasingly documented, their presence in terrestrial environments remains less studied. Horton et al. (2017) reported that plastics released into terrestrial ecosystems are four to twenty-three times higher than in marine environments, yet research on their effects on terrestrial fauna is scarce. MPs have been detected in milk, meat, food products, and blood (Van

Der Veen et al., 2022), as well as in edible species such as earthworms and chickens (Huerta Lwanga et al., 2017).

In Central America, published data are minimal (Ivar Do Sul & Costa, 2014), with only Panama reporting MPs in non-edible crustaceans (Davidson, 2012) and Costa Rica confirming their presence not only in marine environments (Astorga et al., 2022; Johnson et al., 2018) but also in the livers of cattle and pigs intended for human consumption (Soto-Barrientos et al., in press). Despite these advances, knowledge on the occurrence, sources, and impacts of MPs in the country remains limited, underscoring the need for further research to fully understand their implications for public health and the environment. Therefore, this study aims to quantify and characterize microplastics in chicken livers and gizzards intended for human consumption in Costa Rica.

Materials and methods

Samples

A total of 93 chicken livers and 114 gizzards were analyzed, these samples were collected across the country, in the primary meat production regions as follows: livers 33 from Huetar Atlántica, 30 from the Central Region, 21 from Huetar Norte, and 9 from Chorotega; gizzards 54 from the Central Region, 37 from Huetar Atlántica, 13 from Huetar Norte, and 10 from Chorotega (Fig. 1). Sample sizes per region were determined based on availability and logistical constraints.

Therefore, unequal distribution may introduce regional bias, for this reason, statistical comparisons were only made between tissue types. To minimize the risk of contamination from packaging or handling, all samples were placed in clean, airtight containers upon collection and transported on ice to the laboratory.

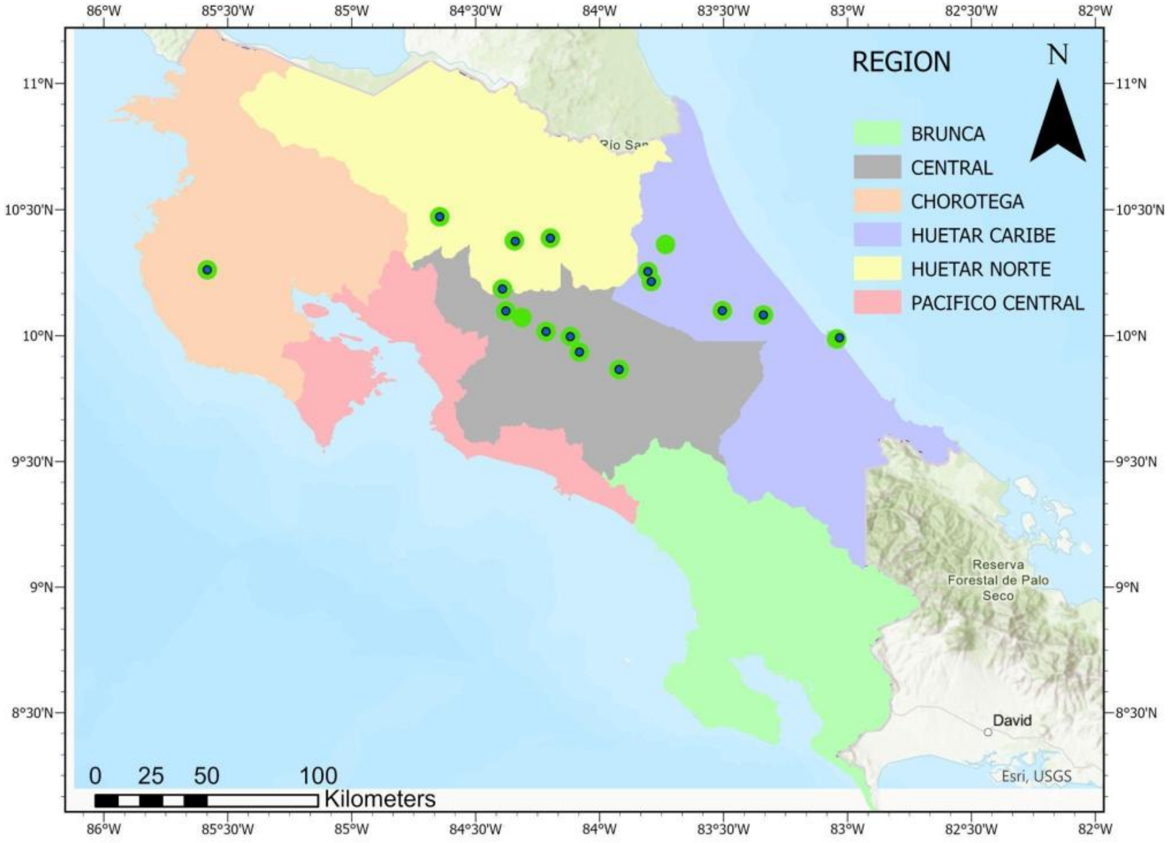

Figure 1. Distribution of sample points in the regions of main meat production in Costa Rica. Green points are liver samples, and blue points are gizzard samples.

Figura 1. Distribución de puntos de muestreo en las principales regiones de producción de carne en Costa Rica. Los puntos verdes corresponden a las muestras de hígados, y los puntos azules a las muestras de mollejas.

Tissue Processing

The tissue process was performed in the Coastal Marine Studies Laboratory (LEMACO) at the School of Biological Sciences from National University of Costa Rica (UNA). All the laboratory implements were rinsed three times with distilled water to reduce possible contamination. Additionally, all glassware was meticulously washed, oven-dried, and covered with aluminum foil when not in use (Astorga et al., 2022). The sample processes were conducted within a laboratory fume hoods, particularly during solution preparation, sieving, and filtration.

For chemical digestion, entire livers and gizzards were processed. The tissue was subjected to chemical digestion with 10% potassium hydroxide (KOH) solution to extract MPs, following the methods described by Cole et al. (2013), Kühn et al. (2017), and Bessa et al. (2019). Samples were incubated at 60°C and 300 rpm for 24 hours in a temperature-controlled orbital shaker. After digestion, the content was sieved through a 60 µm stainless steel sieve and transferred to a clean glass Petri dish. Excess water was evaporated in an oven at 45°C for 30 hours, with dishes covered by perforated aluminum foil to allow evaporation while preventing airborne contamination (Enders et al., 2020).

For quality control of the experiment, 67 negative controls were performed during the treatments with potassium hydroxide, observation, identification and validation of microplastics. All particles identified in these controls were fibers, and any similar particles found at tissue samples were excluded from the analysis (Jabeen et al., 2017).

Identification and Validation of Microplastics

The glass Petri dish with the digest process residual of both types of tissues (livers and gizzards) were examined, and all possible plastics particles retain by sieved between 60 µm to 5000 µm were classified as MPs, those particles were measured and photographed using an OPTIKA SZ-ST2 stereo microscope equipped with an AMSCOPE MU1000 camera and AMPSCOPE software for image analysis (Andrady, 2011), and further categorized by type as fibers (elongated), fragments (irregular pieces), pellets, or films (thin). Additionally, they were categorized by color (Enders et al., 2020; Hidalgo-Ruz et al., 2012; Martin et al., 2017; Qiu et al., 2016). Statistical comparisons were conducted between the MPs concentration (per gram of fresh tissue) in liver tissue and gizzard tissue using paired tests. Prior to selecting the appropriate paired test, normality was assessed using the Shapiro-Wilk test, and variance was tested using the Fisher test (Zar, 2010). Statistical analyses were performed using R Statistical Software (R Core Team, 2020).

FTIR analysis

Microplastic identification was confirmed using Fourier-transform infrared spectroscopy (FTIR) analyses conducted with a Micro-FTIR (Spotlight Frontier System 400) equipped with a mercury-cadmium-telluride detector. Before taking measurements, the detector reservoir was filled with liquid nitrogen, and several parameters were established and controlled as recommended by Andrade et al. (2020) and Rathore et al. (2023).

Point spectra measurement mode was used for MPs identification. A manual mapping of the sample holder was conducted, where each observed particle was subjected to 64 scans in reflectance mode. Particle images were captured using Omnic™ Picta™ software, and the process took several hours per sample. Collected point spectra for each particle were compared against a reference polymer spectrum to achieve chemical identification. The identification was performed using the instrument's libraries or by processing the data with the Open Specy library.

For sample preparation, custom aluminum sample holders, gold-coated with lids to prevent contamination, were specifically designed in collaboration with the Materials Science and Engineering Research Center (CICIMA) at the University of Costa Rica (UCR) for MP analysis. Identified, measured, and photographed particles using an OPTIKA SZ-ST2 stereo microscope were placed in a glass container with ethanol. Suspensions of MP samples in ethanol were carefully deposited onto the gold-coated holders, allowing the ethanol to evaporate completely before proceeding with the analysis. To prevent contamination, the sample containers were washed three times with ethanol to ensure no residual MPs remained. The holders were kept covered with gold-coated lids and stored in a desiccator throughout the process to prevent external contamination.

Results

Liver results

A summary comparison between liver and gizzard results is provided in Table 1. Of the 93 liver samples analyzed, 82.80% (n = 77) tested positive for the presence of MPs, with an average concentration of 0.121 MPs per gram of tissue (±0.15) (Table 1). A total of 353 particles were identified, of which 96.60% (n = 341) were classified as fibers, with an average length of 1551 µm (range: 200–4830 µm). Most of these fibers were blue (35.48%), with the distribution of other colors detailed in Table 2.

Fragments were the second most abundant particle type, with a total of 7 (1.98%), most of which were white translucent (n = 4, 57.14%) and averaged 1614 µm in size (range: 70–4870 µm). The third type detected was films, with five particles (1.42%), all white translucent, and an average size of 1076 µm (range: 650–1370 µm). In total, 353 microplastics were found in 13 908 grams of digested liver tissue, with a cumulative particle length of 545.63 micrometers, resulting in an estimated 0.0392 µm of MPs per gram of digested tissue.

Gizzard results

Out of the 114 gizzards processed, 86.84% (n = 99) tested positive for the presence of MPs. A total of 452 particles were found, of which 96.68% (n = 437) were classified as fibers, with an average size of 1579 µm (range: 220–4980 µm) (Table 1). Many of these fibers were white translucent (40.27%), with the distribution of other colors detailed in Table 2.

Fragments were the second most abundant particle type, with a total of 14 (3.10%), most of which were white translucent (n = 9, 64.29%) and averaged

1636 µm in size (range: 210–3910 µm). The third type detected was one pellet (0.22%), red in color and measuring 1500 µm. In total, 452 microplastics were identified in 11,276 grams of digested gizzard tissue, with a cumulative particle length of 714.44 µm, resulting in an estimated 0.0401 µm of MPs per gram of digested tissue.

Both tissues were compared by the paired Wilcoxon test, because they did not present normality ($p<0.05$) or homoscedasticity ($p<0.05$), resulting in a significant difference between the gizzard tissue and the liver tissue (W = 4149, p-value = 0.0071), with the gizzard tissue having the highest amount of MPs.

Table 1. Comparative microplastic concentrations in chicken liver and gizzard samples.

Tabla 1. Concentraciones comparativas de microplásticos en muestras de hígado y molleja de pollos.

Feature	**Livers**	**Gizzards**
Total samples processed	93	114
Samples with MPs (%)	82.80% (n = 77)	86.84% (n = 99)
Total MPs detected	353	452
MPs per gram (avg ± SD)	0.121 ± 0.15	0.187 ± 0.19
MPs per gram (range)	0.013 – 0.2948	0.013 – 0.2948
FIBERS		
Count (% of total MPs)	341 (96.60%)	437 (96.68%)
Average size (µm)	1551	1579
Size range (µm)	200 – 4830	220 – 4980
Most common color	Blue (35.48%)	White translucent (40.27%)
FRAGMENTS		
Count (% of total MPs)	7 (1.98%)	14 (3.10%)
Average size (µm)	1614	1636
Size range (µm)	70 – 4870	210 – 3910

Most common color	White translucent (57.14%)	White translucent (64.29%)
OTHER PARTICLES		
Films	5 (1.42%), all white translucent, 1076 µm avg (650-1370)	–
Pellets	–	1 (0.22%), red, 1500 µm

Table 2. Color distribution of microplastics by particle shape in chicken livers and gizzards.

Tabla 2. Distribución de color de microplásticos según forma de partícula en hígados y mollejas de pollo.

	Livers			**Gizzards**		
Color	**Fiber n (%)**	**Fragment n (%)**	**Film n (%)**	**Fiber n (%)**	**Fragment n (%)**	**Pellet n (%)**
Black	45 (13.20)	-	-	33 (7.55)	-	-
Blue	121 (35.48)	-	-	148 (33.87)	-	-
Blue and black	-	-	-	1 (0.23)	-	-
Green	3 (0.88)	-	-	3 (0,69)	4 (28,57)	-
Greenish blue	36 (10.56)	-	-	32 (7,32)	-	-
Pink	1 (0.29)	-	-	1 (0.23)	-	-
Purple	3 (0.88)	1 (14.29)	-	4 (0.92)	1 (7.14)	-
Red	10 (2.93)	1 (14.29)	-	12 (0 .75)	-	1 (100.00)
Translucent black	3 (0.88)	-	-	6 (1.37)	-	-
Translucent blue	11 (3.23)	-	-	20 (4.58)	-	-
Translucent colorless	105 (30.79)	4 (57.14)	5 (100.00)	176 (40.27)	9 (64.29)	-
Translucent red	-	-	-	1 (0.23)	-	-

Translucent red and blue	1 (0.29)	-	-	-	-	-
Translucent sky blue	1 (0.29)	-	-	-	-	-
Translucent yellow	1 (0.29)	-	-	-	-	-
White	-	1 (14.29)	-	-	-	-
Total general	**341 (100)**	**7 (100)**	**5 (100)**	**437 (100)**	**14 (100)**	**1 (100)**

FTIR

The preliminary analysis of the spectra obtained by Micro-FTIR revealed several absorption bands that allow the identification of some microplastics. However, the abrasion itself of the MP and the digestion treatment gives deficient resolution and missing areas of the spectrum, therefore the accurate material identification must be performed cautiously. In cases where instrument´s standard spectral libraries were insufficient, it was applied to the Open Specy library for precise MP identification, since this library is constantly updated with sample research spectrums around the world.

The main polymers identified were polypropylene (PP), polyesters, polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyethylene (PE) and alkaline resin. Table 3 shows the polymers identified with a Pearson's correlation coefficient above 0.7 for chicken gizzards and chicken liver.

Table 3. Polymers identified with a Pearson’s correlation coefficient above 0.7 for chicken gizzards and liver.

Tabla 3. Polímeros identificados con un coeficiente de correlación de Pearson superior a 0,7 para mollejas e hígado de pollo.

Sample	PP	Polyester	PVC	PET	PE	Alkaline Resin	Cellulose	Rubber
Chicken Gizzards	3	8	5	1	1	4	N.I.	1
Chicken Liver	8	1	2	4	3	1	3	1

N.I. The polymer was not identified.

Polyester microplastics were found in most chicken gizzards and polypropylene microplastics were found in chicken liver. Other particle spectra in the samples were identified as the same microplastics shown in Table 3, however they are not considered in this study as they have a lower Pearson's correlation coefficient. Poly (diallyl isophthalate) and polyurethane were identified in one particle with a 0.8 Pearson's correlation coefficient, though these results are not conclusive and only give a slight insight of the existence of these microplastics in the sample, therefore more samples are required to confirm these results. Additionally, it was found to be a high average match with cellulose which is a biopolymer and jute fiber, suggesting the presence of natural fibers in the samples.

Discussion

The detection of MPs in chicken livers and gizzards intended for human consumption raises concerns about food safety and environmental contamination, indicating a potential route for plastics into the human diet (Sharma & Vidyarthi, 2024). Given their ubiquity (Galloway & Lewis, 2016), poultry exposure may occur via feed, commonly corn and soybean meal in Costa Rica (INEC, 2023), both reported to contain MPs (Garrido-Gamarro & Constanzo, 2022; Haluska, 2020; Shi et al., 2023; Walkinshaw et al., 2022), as well as through drinking water (Danopoulos et al., 2020). Cross-contamination during slaughter, processing and commercialization is also possible (Garrido-Gamarro & Constanzo, 2022; Lamourou et al., 2022), underscoring the need for contamination controls along the production chain (Sharma & Vidyarthi, 2024).

MP ingestion in poultry has been associated with inflammation, oxidative stress, and impaired nutrient absorption, with possible impacts on gut microbiota and systemic health (Sharma & Vidyarthi, 2024).

The higher MP concentration found in gizzards than in livers aligns with Bilal et al. (2023), reflecting the gizzard's mechanical retention of particles and the potential for MPs to physically degrade there. Detection in livers suggests translocation from the digestive tract into systemic circulation (Sharma & Vidyarthi, 2024).

According to the visual identification criteria for MPs outlined by Zhang et al. (2021), it is essential to consider the shape, size, and color of the MPs. These factors are critical for identifying the type of plastic (Zhang et al., 2021). This information does not clarify the origin of MPs or how these particles end up in animals. The colors of plastics result from the pigments used in their production. For instance, black plastics are often made with polyurethane, transparent plastics typically consist of polypropylene, opaque plastics usually contain low-density polyethylene (LDPE), and white plastics are generally made from polyethylene. In terms of shape, fibers found in urban areas are linked to industrial activities, while fragments are associated with mechanical and chemical degradation processes (Ramachandraiah et al., 2022).

Preliminary Micro-FTIR analysis revealed detection challenges due to sample degradation, polymer blends, and spectral overlaps, consistent with previous studies (Riaz & Ashraf, 2015; Corami et al., 2020). Differentiating synthetic MPs from cellulose fibers is complicated by KOH digestion not removing cellulose (Fendall & Sewell, 2009; Geyer et al., 2017). Suggested improvements include pretreatment to remove natural fibers, density separation, and advanced digestion methods to increase polymer identification accuracy (Enders et al., 2015; Lusher et al., 2013; Hurley et al., 2018).

The identified polymers—polypropylene, polyesters, nylon, PMMA, and PVC—have varying health and environmental risks. PP and PMMA are generally considered safe but can release harmful compounds under certain conditions (Yang et al., 2011; Bettencourt & Almeida, 2015). Polyesters contribute significantly to microfiber pollution and may contain hazardous additives such as antimony (Rudel & Perovich, 2009; Browne et al., 2008; Napper & Thompson, 2016). Nylon production involves toxic chemicals and can emit hazardous fumes when heated (Patel & Bhatt, 2022; Hull & Stec, 2008; Mayer et al., 2024). PVC, widely used in flexible and rigid forms, is highly regulated but its additives can leach over time, raising ecotoxicological concerns (Carroll et al., 2017; Mersiowsky, 2002; Nosova & Uspenskaya, 2023; Nuamzanei et al., 2024; Shen et al., 2023; Sun et al., 2024).

The presence of microplastics in chicken livers and gizzards raises important environmental and health concerns. Identifying the exact sources of this contamination is difficult, but the implications for human health and food safety are substantial. To address this issue, a comprehensive approach is needed, which should include enhanced food safety practices, regulatory measures, public education, and ongoing research to better understand and reduce the risks associated with microplastic contamination in the food supply chain.

Using complementary analytical methods and strict sample preparation protocols is essential for accurately quantifying and identifying microplastics in biological tissues. These measures are crucial for addressing the limitations related to spectral quality and polymer degradation. They will also contribute to the expanding body of research on microplastic contamination in animal tissues. This understanding is vital for evaluating environmental exposure and potential health impacts across different trophic levels.

Conclusions

This study confirms the presence of MPs in chicken livers and gizzards in Costa Rica, adding to recent reports in other livestock species. The findings raise significant concerns for food safety and public health, particularly given the detection of polymers with potential toxicological risks. Challenges in identification highlight the need for advanced analytical methods and larger sample sizes. Reducing MP exposure in the food chain will require coordinated research, stricter contamination controls, and increased public awareness.

Acknowledgements

The work was funded by the Special Fund for Higher Education (FEES) of the National University as part of the project called: 0574-19 Microplastics in terrestrial and marine organisms for human consumption, through the Institutional Fund for Academic Development (FIDA), under which this research was developed. Special thanks to the laboratory assistants who participated in the project: Fausto Arias-Zumbado, Daniela Solis-Adolio, Allison Centeno-Chaves, Andrea Suárez-Baldelomar, Stacy Chacón-Fallas, Keithlyn Rankin-Abraham & Mariana Elizondo-Blanco.

Conflict of interest

Soto-Barrientos, C. Víquez-Murillo, K. Ulate-Naranjo, N. Hernández-Montero, y A. García-Rojas, declares that they have no conflicts of interest.

References

Allen, S., Allen, D., Phoenix, V. R., Le Roux, G., Durántez Jiménez, P., Simonneau, A., Binet, S., & Galop, D. (2019). Atmospheric transport and deposition of microplastics in a remote mountain catchment. *Nature Geoscience*, *12*(5), 339–344. https://doi.org/10.1038/s41561-019-0335-5

Andrade, J. M., Ferreiro, B., López-Mahía, P., & Muniategui-Lorenzo, S. (2020). Standardization of the minimum information for publication of infrared-related data when microplastics are characterized. *Marine Pollution Bulletin*, *154*, 111035. https://doi.org/10.1016/J.MARPOLBUL.2020.111035

Andrady, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin*, *62*(8), 1596–1605. https://doi.org/10.1016/j.marpolbul.2011.05.030

Astorga, A., Montero-Cordero, A., Golfin-Duarte, G., García-Rojas, A., Vega-Bolaños, H., Arias-Zumbado, F., Solís-Adolio, D., & Ulate, K. (2022). Microplastics found in the World Heritage Site Cocos Island National Park, Costa Rica. *Marine and Fishery Sciences (MAFIS)*, *35*(3). https://doi.org/10.47193/mafis.3532022010907

Bessa, F., Kogel, T., Frias, J., & Lusher, A. (2019). Harmonized protocol for monitoring microplastics in biota. In *Micropoll-Multilevel assessment of microplastics and associated pollutants in the Baltic Sea View project* (Issue April). https://doi.org/10.13140/RG.2.2.28588.72321/1

Blettler, M. C. M., Abrial, E., Khan, F. R., Sivri, N., & Espinola, L. A. (2018). Freshwater plastic pollution: Recognizing research biases and identifying knowledge gaps. *Water Research*, *143*, 416–424. https://doi.org/10.1016/j.watres.2018.06.015

Blumenröder, J., Sechet, P., Kakkonen, J. E., & Hartl, M. G. J. (2017). Microplastic contamination of intertidal sediments of Scapa Flow, Orkney: A first assessment. *Marine Pollution Bulletin*, *124*(1), 112–120. https://doi.org/10.1016/j.marpolbul.2017.07.009

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., & Galloway, T. S. (2013). Microplastic Ingestion by Zooplankton. *Environmental Science & Technology*, *47*(12), 6646–6655. https://doi.org/10.1021/es400663f

Cox, K. D., Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F., & Dudas, S. E. (2019). Human Consumption of Microplastics [Research-article]. *Environmental Science and Technology*, *53*(12), 7068–7074. https://doi.org/10.1021/acs.est.9b01517

Danopoulos, E., Twiddy, M., & Rotchell, J. M. (2020). Microplastic contamination of drinking water: A systematic review. *PLOS ONE*, *15*(7), e0236838. https://doi.org/10.1371/JOURNAL.PONE.0236838

Davidson, T. M. (2012). Boring crustaceans damage polystyrene floats under docks polluting marine waters with microplastic. *Marine Pollution Bulletin*, *64*(9), 1821–1828. https://doi.org/10.1016/j.marpolbul.2012.06.005

Dris, R., Imhof, H. K., Löder, M. G. J., Gasperi, J., Laforsch, C., & Tassin, B. (2018). Microplastic Contamination in Freshwater Systems: Methodological Challenges, Occurrence and Sources. In E. Y. Zeng (Ed.), *Microplastic Contamination in Aquatic Environments. An Emerging Matter of Environmental Urgency.* (pp. 51–93). Elsevier, The Netherlands.

Enders, K., Lenz, R., Ivar do Sul, J. A., Tagg, A. S., & Labrenz, M. (2020). When every particle matters: A QuEChERS approach to extract microplastics from environmental samples. *MethodsX*, *7*, 100784. https://doi.org/10.1016/j.mex.2020.100784

Galloway, T. S., & Lewis, C. N. (2016). Marine microplastics spell big problems for future generations. *Proceedings of the National Academy of Sciences*, *113*(9), 2331–2333. https://doi.org/10.1073/pnas.1600715113

Garrido-Gamarro, E., & Constanzo, V. (2022). Microplastics in food commodities. In FAO (Ed.), *Microplastics in food commodities*. FAO. https://doi.org/10.4060/cc2392en

Garza, J. (2019, June). Microplástico podría llegar a su mesa a través de peces y crustáceos. *La República*.

Haluska, K. (2020). *WWU Research Team Examines the Effects of Microplastics and Pesticides on Corn*. Https://News.Wwu.Edu/Wwu-Research-Team-Examines-the-Effects-of-Microplastics-and-Pesticides-on-Corn.

Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the marine environment: A review of the methods used for identification and quantification. *Environmental Science & Technology*, *46*, 3060–3075. https://doi.org/10.1021/es2031505

Horton, A. A., Svendsen, C., Williams, R. J., Spurgeon, D. J., & Lahive, E. (2017). Large microplastic particles in sediments of tributaries of the river Thames,UK—Abundance, sources and methods for effective quantification. *Marine Pollution Bulletin*, *114*(1), 218–226. https://doi.org/https://doi.org/10.1016/j.marpolbul.2016.09.004

Huerta Lwanga, E., Mendoza Vega, J., Ku Quej, V., Chi, J. de los A., Sanchez del Cid, L., Chi, C., Escalona Segura, G., Gertsen, H., Salánki, T., van der Ploeg, M., Koelmans, A. A., & Geissen, V. (2017). Field evidence for transfer of plastic debris along a terrestrial food chain. *Scientific Reports*, *7*(1), 14071. https://doi.org/10.1038/s41598-017-14588-2

Instituto Nacional de Estadistica y Censos (INEC). (2023). *Encuesta Nacional Agropecuaria 2022: Resultados generales de la actividad agrícola y forestal*. https://admin.inec.cr/sites/default/files/202310/reagropecENAAGRÍCOLA2022.pdf

Ivar Do Sul, J. A., & Costa, M. F. (2014). The present and future of microplastic pollution in the marine environment. *Environmental Pollution*, *185*, 352–364. https://doi.org/10.1016/j.envpol.2013.10.036

Jabeen, K., Su, L., Li, J., Yang, D., Tong, C., Mu, J., & Shi, H. (2017). Microplastics and mesoplastics in fish from coastal and fresh waters of China. *Environmental Pollution*, *221*, 141–149. https://doi.org/10.1016/j.envpol.2016.11.055

Johnson, D. E., Ross Salazar, E., Gallagher, A., Rees, A., Sheridan Rodriguez, C., Cambronero Solano, S., Rojas Ortega, G., & Barrio Froján, C. (2018). Preventing plastics pervading an oceanic oasis: Building the case for the Costa Rica Thermal Dome to become a World Heritage site in ABNJ. *Marine Policy*, *February*, 1–8. https://doi.org/10.1016/j.marpol.2018.02.022

Kühn, S., van Werven, B., van Oyen, A., Meijboom, A., Bravo Rebolledo, E. L., & van Franeker, J. A. (2017). The use of potassium hydroxide (KOH) solution as a suitable approach to isolate plastics ingested by marine organisms. *Marine Pollution Bulletin*, *115*(1–2), 86–90. https://doi.org/10.1016/j.marpolbul.2016.11.034

Lamourou, H., Karbout, N., Zriba, Z., Zoghlami, R., Ouessar, M., & Moussa, M. (2022). Green waste biochar effects on sandy soil physicochemical properties. *Journal of Oasis Agriculture and Sustainable Development*. https://doi.org/10.56027/JOASD142022

Martin, J., Lusher, A., Thompson, R. C., & Morley, A. (2017). The Deposition and Accumulation of Microplastics in Marine Sediments and Bottom Water from the Irish Continental Shelf. *Scientific Reports*, *7*(1), 10772. https://doi.org/10.1038/s41598-017-11079-2

Orjuela-Murcia, L. (2019, October). Isla del Coco no se salva de contaminación por microplásticos. *Teletica*.

Qiu, Q., Tan, Z., Wang, J., Peng, J., Li, M., & Zhan, Z. (2016). Extraction, enumeration and identification methods for monitoring microplastics in the environment. *Estuarine, Coastal and Shelf Science*, *176*, 102–109. https://doi.org/10.1016/j.ecss.2016.04.012

R Core Team, D. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. http://www.r-project.org.

Ramachandraiah, K., Ameer, K., Jiang, G., & Hong, G. P. (2022). Micro- and nanoplastic contamination in livestock production: Entry pathways, potential effects and analytical challenges. *Science of the Total Environment*, *844*. https://doi.org/10.1016/j.scitotenv.2022.157234

Rathore, C., Saha, M., Gupta, P., Kumar, M., Naik, A., & de Boer, J. (2023). Standardization of micro-FTIR methods and applicability for the detection and identification of microplastics in environmental matrices. *Science of The Total Environment*, *888*, 164157. https://doi.org/10.1016/J.SCITOTENV.2023.164157

Sharma, P., & Vidyarthi, V. K. (2024). Impact of microplastic intake via poultry products: Environmental toxicity and human health. *Journal of Hazardous Materials Advances*, *14*. https://doi.org/10.1016/j.hazadv.2024.100426

Shi, Y., Yi, L., Du, G., Hu, X., & Huang, Y. (2023). Visual characterization of microplastics in corn flour by near field molecular spectral imaging and data mining. *Science of the Total Environment*, *862*. https://doi.org/10.1016/j.scitotenv.2022.160714

Soto-Barrientos, N., Ulate-Naranjo, K., Víquez-Murillo, C. & García-Rojas, A. (in press). First report of the presence of microplastics in bovine and porcine livers from Costa Rica. Uniciencia.

Van Der Veen, I., Van Mourik, L. M., Van Velzen, M. J. M., Groenewoud, Q. R., & Leslie, H. A. (2022). *Environment & Health Final Plastic Particles in Livestock Feed, Milk, Meat and Blood A Pilot Study*. https://www.plasticsoupfoundation.org/rapporten/Final-Report-pilot-study-plastic-particles-in-livestock-feed-milk-meat-and-blood.pdf

Walkinshaw, C., Tolhurst, T. J., Lindeque, P. K., Thompson, R., & Cole, M. (2022). Detection and characterisation of microplastics and microfibres in fishmeal and soybean meal. *Marine Pollution Bulletin*, *185*. https://doi.org/10.1016/j.marpolbul.2022.114189

Zar, J. H. (2010). *Biostatistical Analysis* (5th ed.). Pearson Prentice Hall.