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Presencia de microplásticos en pequeños rumiantes de sistemas pastoriles del litoral ecuatoriano

Microplastics in Small Ruminants from Pastoral Systems of the Ecuadorian Coast

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Resumen
El estudio detectó partículas compatibles con microplásticos (MP) en pequeños rumiantes de sistemas pastoriles del litoral ecuatoriano, lo que sugiere una posible exposición ambiental a este tipo de contaminantes. Para ello, se analizaron 200 muestras fecales de cabras y ovejas mediante técnicas de flotación en solución sobresaturada de NaCl y digestión alcalina, evidenciándose la presencia de partículas compatibles con MP en el 100 % de los individuos evaluados. Además, la concentración promedio fue de 4.95 MP/g; aunque las concentraciones medias fueron similares entre especies/sistemas, la comparación inferencial de MP/g requiere datos individuales por muestra. Asimismo, más del 80 % de las partículas observadas correspondieron a fibras, lo que podría estar relacionado con fuentes de contaminación presentes en sistemas pastoriles, como residuos textiles, plásticos agrícolas en degradación o materiales fibrosos del entorno rural. De igual forma, se observaron patrones cromáticos diferenciados: las cabras, procedentes de zonas áridas, presentaron mayor presencia de partículas oscuras, mientras que las ovejas, vinculadas a ambientes más húmedos, presentaron mayor proporción de partículas

claras. Estas diferencias permiten plantear posibles rutas de exposición ambiental, aunque requieren confirmación mediante el análisis de matrices como suelo, agua, pasturas y alimento. Las partículas fueron clasificadas morfológicamente como microplásticos sospechosos mediante microscopía óptica; por ello, se recomienda la confirmación del polímero mediante espectroscopía FTIR o Raman. En consecuencia, los hallazgos aportan evidencia preliminar sobre la presencia de partículas compatibles con MP en heces de pequeños rumiantes y justifican estudios posteriores que evalúen su composición, origen ambiental y posible relación con matrices pecuarias y productos de origen animal.

Palabras clave: microplásticos; cabras; ovejas; heces; litoral ecuatoriano; fibras microplásticas.

Abstract
This study detected particles compatible with microplastics (MPs) in small ruminants from pastoral systems along the Ecuadorian coast, suggesting possible environmental exposure to this type of contaminant. A total of 200 fecal samples from goats and sheep were analyzed using flotation in a supersaturated NaCl solution and alkaline digestion, showing the presence of particles compatible with MPs in 100% of the evaluated individuals. The average concentration was 4.95 MP/g; although mean concentrations were similar between species/systems, inferential comparison of MP/g requires sample-level data. More than 80% of the observed particles corresponded to fibers, which may be related to contamination sources present in pastoral systems, such as textile residues, degrading agricultural plastics, or fibrous materials from rural environments. Likewise, differentiated chromatic patterns were observed: goats from arid areas showed a higher presence of dark particles, whereas sheep associated with more humid environments showed a higher proportion of light-colored particles. These differences allow possible environmental exposure routes to be proposed, although they require confirmation through the analysis of matrices such as soil, water, pasture, and feed. Particles were morphologically classified as suspected microplastics by light microscopy; therefore, polymer confirmation using FTIR or Raman spectroscopy is recommended. Consequently, the findings provide preliminary evidence of the presence of particles compatible with MPs in feces from small ruminants and justify further studies to evaluate their composition, environmental origin, and possible relationship with livestock matrices and animal-derived products.

Keywords: microplastics; goats; sheep; feces; Ecuadorian coast; microplastic fibers.

Introduction

Microplastic pollution has become a global environmental concern, with documented impacts on terrestrial and aquatic ecosystems (Landrigan et al., 2023). These plastic particles, measuring less than 5 mm, are ubiquitous and have been detected in water sources, soils, food products, and even within the tissues of living organisms (Celi-Simbaña et al., 2023). Their persistence in the environment is largely attributed to the slow degradation of synthetic polymers, which facilitates their entry into food webs and their subsequent bioaccumulation (Kanwal et al., 2023).

Microplastic contamination significantly affects marine and terrestrial environments, where it can alter soil quality, be ingested by organisms,

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and act as a physical barrier that disrupts environmental balance (Aransiola et al., 2025). These authors highlight that microplastics in terrestrial environments originate from multiple sources, including the textile industry, sewage sludge, and agricultural plastic mulches.

In agricultural contexts, small ruminants such as sheep and goats are particularly exposed to microplastic ingestion through grazing, contaminated water consumption, and supplemental feeding (Beriot et al., 2021). Recent studies have shown that microplastics can be accidentally ingested during foraging and transported throughout the digestive tract, being partially excreted or accumulating in tissues (González-Puetate et al., 2024). This represents a potential risk not only for animal health but also for the safety of animal-derived food products intended for human consumption (Urli et al., 2023).

Despite the growing evidence of microplastics in livestock systems, studies focusing on small ruminants remain limited, particularly in Latin America. Research such as that conducted by Caicedo Olvera and Paguay Paguay (2024) in the province of Guayas, Ecuador, reported 100% microplastic contamination in fecal, water, and diet samples from sheep, indicating widespread environmental exposure. However, a synthesis of existing findings is needed to better understand the magnitude of this issue across different production systems.

Therefore, this study aimed to determine the frequency, concentration, morphology, and color of suspected microplastics in fecal samples from goats in Manabí and sheep in Guayas, Ecuador, and to compare concentrations and particle categories between species/systems.

Materials and Methods

Study design and sampling: This was an observational, cross-sectional study conducted in small ruminants from pastoral production systems on the Ecuadorian coast. The study included fecal samples from goats (Capra aegagrus hircus) raised in rural areas of Manabí province and sheep (Ovis aries) raised in Guayas province, including the Pedro Carbo and Naranjal cantons, according to the production systems described for each group. The experimental unit was each individual animal and its corresponding fecal sample.

A total of 200 animals were evaluated, distributed in two balanced groups: 100 goats and 100 sheep. The sample size was defined by the availability of animals in participating production units and by balanced allocation between species/systems to allow descriptive and comparative analysis. Therefore, the sampling strategy was non-probabilistic and based on convenience, with individual selection of animals within the available herds. The comparisons were interpreted as species/system comparisons because goats and sheep came from different production contexts and geographical areas.

The inclusion criteria were: clinically healthy small ruminants raised under extensive or semi-intensive pastoral systems, animals with identifiable species, sex, age range and breed, and animals present in the production unit during the sampling period. Age was obtained from farm records when available and complemented with owner information and field verification. Animals with diarrheic feces,

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visibly contaminated fecal material, recent confinement outside the usual production system, or incomplete identification data were excluded. Before sampling, authorization was obtained from the owners or managers of the production units. Since the study involved fecal sampling and did not include invasive procedures, experimental treatments or clinical intervention, the risk for animal welfare was minimal.

Fecal sample collection and contamination control: Fecal samples were collected individually using disposable gloves and clean glass or sterile containers. To reduce the risk of external contamination, samples were obtained immediately after observed defecation before contact with soil whenever possible; fecal material with evident contact with soil, bedding, plastic residues or foreign particles was discarded. Each sample was labeled with a unique code including species, sampling site, sex, age range and date of collection. Samples were transported under clean conditions and processed as soon as possible after collection.

During field and laboratory handling, contamination control measures were applied. Plastic materials were minimized during collection and processing; glassware was used whenever possible; samples and cylinders were covered with aluminum foil; work surfaces were cleaned before processing; and observations were performed in a controlled area to reduce airborne contamination. The particles reported in this study were considered suspected microplastics because they were classified by morphology and color under light microscopy, without polymer confirmation by FTIR or Raman spectroscopy. Procedural blanks were not included; therefore, future studies should incorporate field and laboratory blanks to better quantify potential background contamination.

Density separation and alkaline digestion: The density separation procedure was based on a modified Willis-Molloy technique. A supersaturated sodium chloride (NaCl) solution was prepared and used to float low-density particles based on density differences. For each sample, 2 g of feces were placed in glass cylinders with 28 mL of the saline solution, homogenized using a glass stirrer, and covered with aluminum foil to prevent cross-contamination. The cylinders were incubated at 37.5 °C for 4 h, allowing floating particles to rise to the surface.

The supernatant obtained after flotation was subjected to alkaline digestion to remove residual organic matter. In the original analytical procedure, goat samples were treated with 10% potassium hydroxide (KOH), whereas sheep samples were treated with 10% sodium hydroxide (NaOH). Because the use of different alkaline reagents may influence particle recovery or alteration, this condition was explicitly considered a methodological limitation when comparing species/systems. The same sample weight, flotation solution, incubation time, aliquot volume, microscopic magnification and counting criteria were maintained for both groups to reduce procedural variability. Future studies should standardize a single validated digestion reagent for all species before direct interspecific comparison.

After digestion, a 10 µL aliquot of the supernatant was carefully extracted using a Pasteur pipette, placed on a clean glass slide and covered with a coverslip. Observation was

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performed under a light microscope at 10× to 40× magnification. Particles were preliminarily classified as suspected microplastics based on morphological criteria such as shape, color, lack of cellular structure and visual consistency with fibers or fragments.

Quantification of suspected microplastics: The concentration of suspected microplastics per gram of feces (MP/g) was calculated by relating the number of particles observed in the aliquot to the total volume of the supernatant and the weight of the processed fecal sample. The calculation considered the number of suspected particles counted in the 10 µL aliquot, the total supernatant volume obtained after separation and the analyzed fecal weight of 2 g. The final value was expressed as MP/g, allowing descriptive comparisons between the two species/systems.

Statistical analysis: Data were organized in Microsoft Excel 2024 and analyzed using IBM SPSS Statistics version 26.0. Descriptive statistics were used to summarize the frequency of positive samples, total suspected particles, concentration expressed as MP/g, particle morphology and particle color. For MP/g concentration per sample, normality was assessed using the Shapiro-Wilk test. When assumptions of normality and homogeneity of variances were met, the independent-samples t-test was used to compare goats and sheep; otherwise, the Mann-Whitney U test was applied. Results for quantitative variables were reported as mean ± standard deviation or median and interquartile range, according to distribution, together with the exact p-value, 95% confidence interval and effect size.

For categorical variables, including morphology (fibers/fragments), contingency tables were analyzed using Pearson's chi-square test (χ^2). Fisher's exact test was considered when expected frequencies were lower than five. Morphological comparisons were reported with the test statistic, degrees of freedom, exact p-value and Cramer's V as effect size. Color category (light/dark) was retained as a descriptive variable because the available aggregated color data were not sufficient for valid inferential analysis. When particle counts were analyzed directly, Poisson or negative binomial models were considered according to the presence of overdispersion. A significance level of $\alpha = 0.05$ was used for all analyses. Since species and geographical/production system were not fully independent factors in the study design, statistical differences were interpreted cautiously as exploratory species/system associations rather than causal species effects.

Results and discussion

A total of 200 fecal samples were analyzed, corresponding to 100 goats from pastoral systems in Manabí and 100 sheep from pastoral systems in Guayas. **Table 1** summarizes the sampling design and the main population characteristics without separating these elements into different tables, in order to avoid redundancy. Because species, province and production system were linked in the study design, comparisons are interpreted as exploratory species/system associations rather than independent species effects.

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Table 1. Sampling design and descriptive characteristics of small ruminants evaluated in coastal Ecuador

Characteristic	Goats-Manabí	Sheep-Guayas
n	100	100
Province/cantons	Manabí; rural dry-forest areas	Guayas; Pedro Carbo and Naranjal
System	Extensive pastoral	Extensive to semi-intensive pastoral
Sex	F 59%; M 41%	F 52%; M 48%
Age	2-4 years	1-3 years
Breed	Criolla / Anglo-Nubian	Criolla / Pelibuey

Note: Sample size corresponds to animals/fecal samples. Convenience sampling; clinically healthy animals with complete identification were included. Herd number was unavailable.

The production context is summarized in **Table 2.** These variables are presented only to contextualize possible exposure conditions; they should not be interpreted as demonstrated sources of contamination because water, soil, forage, feed, dust and other environmental matrices were not analyzed for microplastics in the present study.

Table 2. Management and feeding context of the evaluated systems

Variable	Goats-Manabí	Sheep-Guayas
Management	Extensive grazing; night shelter	Extensive/semi-intensive grazing; partial confinement
Feeding	Forages, shrubs and wild grasses; no concentrate	Pastures and crop residues; no concentrate
Water	Ponds and artisanal wells	Rivers and local ponds
Grazing context	Homogeneous goat herds	Near or with other livestock areas
Grazing time	8-10 h/day	8-9 h/day
Sampling period	Mar 2024; rainy-dry transition	Apr-May 2024; dry season

Note: Contextual variables only; they do not establish causal sources of the suspected particles detected in feces.

Based on the contextual information, potential exposure routes were organized as hypotheses rather than empirical source attributions **Table 3**. This restructuring avoids assigning origin to particles solely from color, morphology or production setting. Confirmation requires environmental sampling and polymer identification.

Table 3. Potential exposure routes and analyses required for confirmation

System	Route hypothesis	Confirmation needed
Goats-Manabí	Dry forage/soil/dust; ponds/wells	Soil, dust, forage, water; FTIR/Raman
Sheep-Guayas	Pastures/crop residues; runoff water/ponds	Pasture, feed, water, sediment; FTIR/Raman

Note: Hypothesis-generating table; direct environmental measurements are required to confirm exposure routes.

Suspected microplastic particles were observed in all fecal samples analyzed by light microscopy. This result indicates the presence of particles morphologically compatible with microplastics in feces, but it does not confirm polymer composition. Therefore, the results should be interpreted as preliminary detection of suspected microplastics pending spectroscopic confirmation by FTIR or Raman.

After arithmetic verification of the morphology counts, 1,980 suspected particles were retained for analysis. The corrected totals indicate 1,650 fibers and 330 fragments in the complete sample, equivalent to 83.3% and 16.7%, respectively. Goats showed 910 fibers and 70 fragments, whereas sheep showed 740 fibers and 260 fragments. Thus, fibers were the predominant morphology in both species/systems; however, this predominance was proportionally higher in goats than in sheep **Table 4**.

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Table 4. Quantification of suspected microplastics, morphology and average concentration

System	n; total MP	Morphology	Mean MP/g
Goats-Manabí	100; 980	F 910 (92.9%); Fr 70 (7.1%)	4.90
Sheep-Guayas	100; 1,000	F 740 (74.0%); Fr 260 (26.0%)	5.00
Total	200; 1,980	F 1,650 (83.3%); Fr 330 (16.7%)	4.95

Note: F = fibers; Fr = fragments. Morphology differed between species/systems: chi-square(1) = 126.72; p = 2.14 x 10^-29; Cramer's V = 0.253. MP/g comparison requires sample-level data.

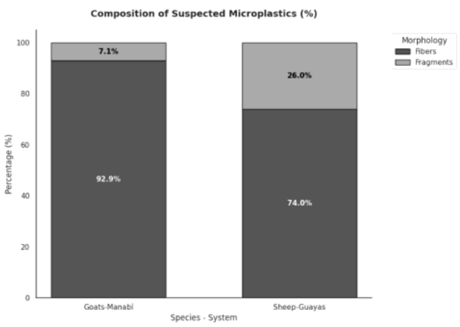

Figure 1. Distribution of suspected microplastic morphology in fecal samples from goats and sheep.

The predominance of fibers is consistent with reports that fibrous particles are frequent in agricultural and livestock environments where textile residues, ropes, sacks, plastic agricultural materials and other synthetic fibers may be present (Mohammadi et al., 2025; Sheriff et al., 2023; Weithmann et al., 2018). Nevertheless, the present study did not analyze environmental sources or polymer composition; therefore, the association between fibers and specific contamination sources remains a plausible interpretation rather than a demonstrated causal pathway.

The literature indicates that manure, digestates and livestock compost can contribute to the redistribution of microplastics into agricultural soils (Quilliam et al., 2023; Rana et al., 2023). In the evaluated systems, the presence of suspected particles in feces suggests that fecal material could participate in local redistribution if used as organic amendment. This interpretation should be tested through parallel analysis of manure, soil, pasture and water under the same production conditions.

Climate and management may influence the mobility of plastic particles in pastoral landscapes. Dry environments can favor surface accumulation and wind resuspension of particles (Evangelou et al., 2024; Rezaei et al., 2022), whereas humid environments can facilitate transport by rainfall and runoff toward rivers, drainage channels and flooded areas (Severe et al., 2025). These mechanisms help contextualize the Manabí and Guayas systems, but they remain explanatory hypotheses because the study did not directly measure microplastics in air, soil, runoff or water bodies.

Particle color was retained as a descriptive observation but was not presented as a separate quantitative table because the available aggregated color values were not consistent with the overall concentration of 4.95 MP/g. Without the original particle-level database by color and species/system, it is not possible to calculate total particles, percentages, mean +/- SD, exact p-values or effect sizes for color categories. Accordingly, chromatic findings should be interpreted only as visual tendencies: darker particles were more frequently described in goat samples, whereas lighter particles were more frequently described in sheep samples.

Color alone does not identify source, polymer type or exposure route.

Overall, the observed morphology and color patterns generate hypotheses about exposure pathways; confirmation requires simultaneous analysis of soil, water, forage and polymer composition. The findings support the need for integrated monitoring of fecal and environmental matrices in small ruminant systems on the Ecuadorian coast, while avoiding causal claims about specific sources or sanitary implications that were not directly evaluated in the present study.

Conclusions

This study detected suspected microplastic particles in fecal samples from goats and sheep in two coastal Ecuadorian systems. Similar mean concentrations were observed between goats and sheep; however, species and site effects cannot be separated in the current design because each species was associated with a different province and production system.

A predominance of fibers over fragments was identified among the recovered particles. Nevertheless, this finding should be interpreted as a morphological pattern of the suspected particles observed in feces rather than as direct evidence of specific contamination sources, since environmental matrices such as soil, water, forage and feed were not analyzed simultaneously.

Chromatic differences may reflect different environmental sources, but this should be tested with environmental sampling and polymer identification. Therefore, the observed color patterns should be considered exploratory and useful for generating hypotheses about possible exposure pathways, rather than confirming terrestrial, aquatic or atmospheric sources.

The flotation/digestion protocol allowed preliminary isolation and morphological characterization of suspected microplastic particles in fecal samples; however, its analytical performance should be validated in future studies. Polymer confirmation using FTIR or Raman spectroscopy is recommended to strengthen particle identification and reduce uncertainty associated with visual classification by light microscopy.

The findings support the potential use of small ruminants as sentinels of environmental exposure; future research should evaluate toxicological effects and possible transfer to animal-derived products. Further studies should also incorporate environmental matrices, standardized digestion procedures and confirmatory polymer analysis to better understand the origin, distribution and implications of suspected microplastics in pastoral livestock systems.

Conflict of interest

The authors declare that there is no conflict of interest.

Contribución de los autores

Conceptualization: I.G.P., G.G.E., D.P.C.; Methodology: I.G.P., E.V.M., B.A.P.; Investigation: I.G.P., E.V.M., B.A.P.; Formal Analysis: I.G.P., G.G.E., D.P.C.; Writing—Original Draft Preparation: I.G.P., G.G.E., E.V.M., B.A.P., D.P.C.; Writing—Review and Editing: I.G.P., B.A.P, G.G.E.; Supervision: D.P.C., I.G.P.

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