MICROPLASTICS AND NANOPLASTICS IN THE FOOD CHAIN OF FARM ANIMALS: IMPACTS ON HEALTH AND PRODUCTIVITY

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Abstract

Pollution from microplastics (MP) and nanoplastics (NP) has emerged as a central concern in environmental and health research. While most studies focus on aquatic ecosystems, recent evidence highlights direct contamination of livestock farms through feed, water, soil, and equipment. Ingested particles disrupt the gut microbiome, inducing dysbiosis, local and systemic inflammation, and reduced digestive efficiency. Chronic exposure is associated with metabolic disorders, oxidative stress, and liver dysfunction, with consequences for growth, reproduction, and overall productivity. Detection of plastics in milk, meat, and eggs suggests direct transfer to consumers, raising significant food safety and public health concerns. Within the One Health framework, these findings emphasize the interdependence of animal, human, and environmental health, underlining the urgent need for monitoring, risk mitigation, and integrated management strategies. This paper provides an integrated review of exposure sources, physiological effects, and broader health implications of MNP in animal production.

Key words: *gut microbiome, livestock, microplastics, nanoplastics, one health.*

INTRODUCTION

Plastics have been widely used in manufacturing and daily life due to their durability, stability, versatility, and low cost. Their popularity has driven an exponential increase in global production, from approximately 2 million tonnes in 1950 to about 414 million tonnes in 2023. Today, terms such as the "Plastic Age" or even "Plasticene" are used to describe the magnitude of this global phenomenon [1]. The increase in plastic consumption has been driven primarily by industries such as packaging and construction; however, the extremely short life cycle of many plastic products, particularly single-use items, has created a major waste management challenge with significant social, economic, and public health implications [2]. Exposure of plastic waste to physical, chemical, and biological factors leads to the formation of microplastics (MPs, <5 mm) and nanoplastics (NPs, <0.1 µm), particles characterized by high persistence and a ubiquitous global distribution in water, soil, and air. These particles not only accumulate in the environment but also interact with various chemical contaminants (e.g., heavy metals, pesticides, persistent organic pollutants) and biological agents (bacteria, fungi, algae), thereby facilitating their transfer within ecosystems and amplifying ecotoxicological effects [3,4,5]. Although most studies have focused on marine ecosystems, an increasing body of evidence indicates the presence of micro- and nanoplastics in agroecosystems and terrestrial food chains, including

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conventionally managed agricultural soils [6]. However, the current literature remains marked by significant uncertainty regarding the actual levels of exposure, mechanisms of toxicity, and impacts on animal and human health, highlighting the need for further in-depth research [7]. In livestock farming systems, animals may be exposed to micro- and nanoplastics (MNPs) through contaminated feed, water, soil, and farm equipment. Ingestion of these particles can alter the gut microbiome, inducing dysbiosis and inflammation, thereby reducing digestive efficiency and affecting energy and lipid metabolism [8]. Furthermore, MNPs can cross biological barriers and accumulate in vital organs such as the liver, leading to oxidative stress, hepatic injury, and metabolic dysfunctions [9]. These physiological disturbances may result in reduced productivity and altered quality of animal-derived products (milk, meat, eggs), with serious implications for food safety and public health [10].

The aim of this study is to provide a critical synthesis of recent literature on the occurrence of micro- and nanoplastics (MNPs) in livestock farms, their sources of contamination, and their effects on animal health. The review seeks to highlight the mechanisms through which MNPs can affect the gut microbiome, metabolic functions, and hepatic physiology, as well as how these disturbances may impact the quality of animal-derived products.

Furthermore, the analysis aims to contextualize these findings within the One Health framework, emphasizing the potential risks to public health and the need for multidisciplinary strategies to monitor and mitigate the impact of plastic pollution.

MATERIAL AND METHOD

This narrative review is based on an analysis of recent scientific literature on the contamination of livestock farms with micro- and nanoplastics (MNPs). Literature searches were conducted in major academic databases (PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar), selected for their broad coverage of veterinary sciences, agriculture, and food safety. The time frame considered was 2016-2025, to capture the most recent data on the sources, mechanisms, and effects of MNP exposure. Both experimental studies on animal models and narrative or systematic reviews were included, based on their relevance to the research topic. Selection criteria focused on studies describing the occurrence and effects of MNPs in feed, water, and farm equipment, their impact on animal health and productive performance, and the potential transfer of these particles to humans through animal-derived food products.

SOURCES OF MICRO- AND NANOPLASTIC CONTAMINATION IN LIVESTOCK FARMS

The contamination pathway of micro- and nanoplastics (MNPs) in livestock farms originates from the surrounding environment and encompasses multiple entry points, including feed, water, equipment, and agricultural practices. Studies indicate that MNPs derive both from the degradation of environmental plastic waste (e.g., lawns, farms, feeding areas) and from plastics used directly in animal husbandry [11]. For instance, soil mulching with plastic films, plastic silos for feed, or plastic packaging of feed and fertilizers promotes the fragmentation of plastics into smaller particles. Furthermore, the application of sewage sludge to agricultural fields disperses MNPs into the soil [12]. Even in industrial farms with advanced waste management systems, plastic fragments have been detected in feeding installations and in the barn air [13].

Contaminated feed **-** Animal feed can be contaminated with microplastics through multiple pathways. Ingredients sourced from contaminated environments (e.g., fishmeal or marine algae) or during storage and handling in plastic packaging can release plastic fragments. Consequently, some studies have reported the presence of tens to hundreds of plastic particles per kilogram of feed [14,15]. "Feeds are frequently contaminated with micro- and nanoplastics originating from degraded agricultural residues, contaminated soil, or processing and packaging materials." Furthermore, the storage of feed in silos or plastic bags can lead to mechanical contamination (e.g., through friction with plastic surfaces, generating plastic dust) [13]. In some cases, feed provided to poultry and pigs has been shown to contain hundreds of plastic particles per kilogram distributed on farms [16].

Drinking water **-** Water provided to livestock can serve as a source of micro- and nanoplastics (MNP) if it originates from contaminated sources, such as groundwater or storage tanks. Fine plastic particles from the atmosphere can also deposit into water (e.g., via contaminated rainfall), and water supply systems (pipes and plastic reservoirs) may release fragments [17]. Leaks from plastic tanks and pipelines are major contamination routes in mixed-pasture farms. Even municipal or well water can contain microplastics, which accumulate in the gastrointestinal tract of animals upon consumption [11].

Equipment and packaging **-** The use of plastic equipment in farms (barns, feeding trays, irrigation tubes, pasteurization hoses, veterinary medical devices, etc.) can generate microscopic particles through wear or UV degradation. For example, during the opening of plastic packaging for feed or supplements, releases of tens to hundreds of particles per cm^2 of surface have been measured [18,19]. In livestock houses, dust generated from the abrasion of plastic materials (e.g., during hay handling or scratches on tubing) contributes to airborne microplastics, which can be inhaled by animals or settle on feed and water [20].

Agricultural Environment **-** Farm soils can become enriched with micro- and nanoplastics (MNPs) through the use of mulching or silage films (polyethylene), crop protection materials, as well as illegal waste disposal. Additionally, animals can directly absorb MNPs from the environment through accidental ingestion during grazing [21]. Aardema et al. (2024) note that grazing on soils covered with plastic mulch or on fields treated with sewage sludge exposes animals to tens to hundreds of plastic particles per square meter [12, 22]. A study conducted on free-range chickens identified approximately 129,800 particles per kilogram in feces and 14,800 particles per kilogram in soil near manure, in proximity to uncontrolled plastic waste deposits. Over time, the fragmentation of plastics within the farm environment thus creates a persistent reservoir of MNPs that eventually enter the food chain [23]. Farm animals may ingest micro- and nanoplastics (MNPs) from contaminated feed, water, and soil, while plastic degradation and agricultural wastes further contribute to their accumulation in the environment and entry into the food chain [24] (Figure 1).

DETECTION AND QUANTIFICATION METHODS FOR MICRO- AND NANOPLASTICS

The analysis of micro- and nanoplastics (MNPs) in livestock-related samples (feed, water, soil, biological tissues) involves several successive stages: sampling, chemical digestion, density separation, filtration, and identification [25]. Chemical treatments (using hydrogen peroxide, enzymes, or alkaline solutions) serve to remove organic matter while preserving the plastic particles. Several complementary methods are employed for the identification and quantification of MNPs, each with specific advantages and limitations [26]. Table 1 summarizes these methods and their respective fields of application.

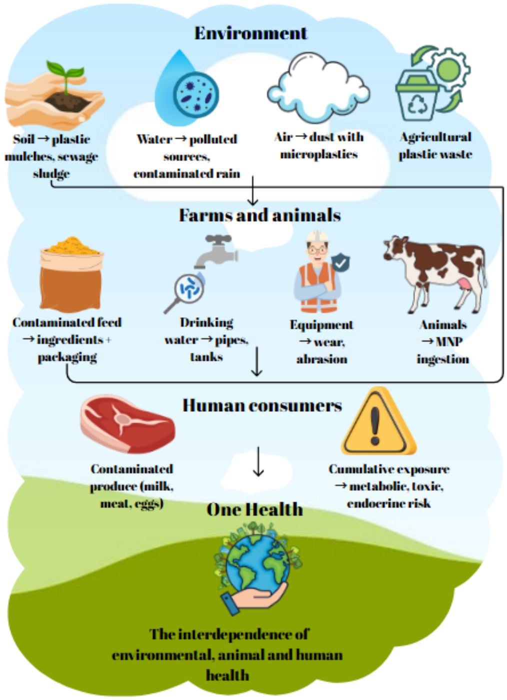

Fig. 1. Flow of micro- and nanoplastics in the food chain

Table 1. Methods for the detection and quantification of micro- and nanoplastics in livestock farming

Method	Principle	Detected size	Advantages	Limitations/ Challenges	Reference
Optical microscopy + fluorescent staining (Nile Red)	Visual observation of stained particles	>20 µm	Rapid and useful for visual screening of feed and water samples	Does not detect nanometric particles; may overestimate due to organic particle interference	[27]
FTIR / Raman spectroscopy	Identification of polymer type	>1-20 µm	„Considered the gold standard" for polymer identification	Requires expensive instrumentation and is time-consuming	[25]
Electron microscopy (SEM/TEM)	High-resolution imaging	<1 µm	Provides detailed morphology and nanometric size information	Expensive; sample preparation is complex	[28]
Thermal / chromatographic analyses (Py-GC/MS, TED-GC/MS)	Measures total polymer mass	All sizes	Determines the total plastic content in the sample	Does not provide morphological information	[11]
Near-infrared (NIR) spectroscopy	Rapid assessment of contamination	>micrometric	Promising for routine applications and rapid monitoring	Emerging method; standards are still limited	[13]

The major challenges are associated with the small size of the particles, the complexity of biological matrices (fiber-rich feed, animal tissues), and the lack of a universal standard method. Consequently, reported results in the literature vary considerably [28].

ISO standard 24187:2023 and JRC/EFSA guidelines have recently set minimum methodological requirements (sampling, processing, and data reporting); however, harmonized protocols for livestock samples are still lacking [29].

EFFECTS OF MICROPLASTICS AND NANOPLASTICS ON THE INTESTINAL MICROBIOME

As previously highlighted, feed and water are the main sources of MNP exposure on farms, facilitating the ingestion of particles that interact with the intestinal microbiota. Ingested micro- and nanoplastics induce imbalances and inflammatory responses. Intestinal dysbiosis is frequently observed, characterized by reduced bacterial diversity and significant alterations in microbial community composition [30,31]. In a recent experimental study on chickens exposed to microplastics, alpha diversity of the intestinal microbiota decreased significantly, and the relative abundances of key bacterial genera were markedly altered. For example, populations of *Proteobacteria* (potentially beneficial bacteria) were reduced, whereas others (e.g., *Cyanobacteria*) increased abnormally. These changes indicate pronounced dysbiosis, with potentially adverse effects on digestion and intestinal health [27, 32].

Zou et al. (2023) conclude that microplastic exposure “leads to intestinal microbial imbalance” and suggest that this effect exacerbates metabolic stress in the animal [27].

Microbiota imbalance **-** Studies indicate that microplastics significantly alter the composition of the intestinal flora. Zhou et al. (2025) demonstrated that chronic exposure to polystyrene particles (PS-MPs) modifies the diversity and abundance of intestinal bacteria in chickens, reducing certain species to near disappearance while allowing others to proliferate [33].

Moreover, ingested plastics can adsorb or release chemical compounds (plasticizers, additives) that disrupt the microbial environment and select for microbiota resistant to oxidative stress. Altogether, these processes lead to decreased digestive efficiency (due to reduced microbial enzyme activity) and an increased risk of gastrointestinal disturbances [34].

Local inflammation **-** In addition to alterations in the microbial community, MNPs can induce inflammation at the intestinal mucosal level. For example, studies in ducks and frogs have shown that polystyrene plastic particles promote mucosal damage and lymphocyte infiltration in the intestine, indicating a localized inflammatory response [33]. Exposure to PS-MPs increases the levels of microbial endotoxins (LPS) in the intestine and bloodstream, activating inflammatory pathways (TLR4/NF-κB) that amplify systemic inflammation. This intestinal inflammation negatively affects nutrient absorption (through disruption of the epithelial barrier) and may impair the animal’s immune and metabolic functions [35].

Digestive and fermentative function –

In ruminants and poultry, microplastics also affect ruminal fermentation and feed degradation processes [6]. An in vitro study on ruminal fluid from ewes demonstrated that contamination with polyethylene terephthalate (PET), low-density polyethylene (LDPE), and polyamide (PA) particles disrupted fermentation dynamics: gas generation time decreased, total gas production increased, and feed degradability was significantly reduced.

Plastic particles lowered microbial efficiency (fewer ruminal protozoa), increased ammonia (NH_3-N) concentration, and accelerated fermentation rates. In practice, feed contaminated with microplastics is less digestible, resulting in potential energy and nutrient losses in ruminants, thereby affecting growth and productivity. Consequently, this may lead to reduced feed conversion efficiency and lower milk or meat yields [36, 37].

The ingestion of micro- and nanoplastics triggers harmful effects on the intestinal microbiome, reducing bacterial diversity, altering species balance, inducing local inflammation, and disrupting digestive processes [38].

This dysbiosis, accompanied by increased gut permeability and inflammation, may facilitate the translocation of bacteria and toxins into systemic circulation, amplifying oxidative stress and immune responses [39]. Evidence from poultry and ruminants shows that microplastics disrupt intestinal flora, causing subclinical symptoms (e.g., reduced appetite, mild diarrhea) and, over time, decreased animal productivity [16, 40].

IMPACT ON METABOLISM AND LIVER FUNCTION

Once in the body, micro- and nanoplastics can be absorbed in small amounts and accumulate in vital organs, particularly the liver, which serves as the primary organ for detoxification and metabolic homeostasis [41].

Experimental studies, conducted on both farm animals and laboratory models (mice, ducks), indicate that micro- and nanoplastics (MNPs) induce oxidative stress, chronic inflammation, and disturbances in energy and lipid metabolism. These alterations can impair liver function, affecting metabolic efficiency, biochemical profiles, and overall animal health [42, 43].

A clear summary of the main effects on the liver is presented in Table 2.

Table 2. Effects of micro- and nanoplastics on metabolism and liver function in farm animals and experimental models

Mechanism/Target	Particle type	Experimental model	Biological/ Metabolic effect	Reference
Oxidative stress, NF-κB, pro-inflammatory cytokines (TNF-α, IL-6, IL-1β)	PS-MPs	Ducks	Stress-induced hepatitis, chronic inflammation	[33]
Gut-liver axis (increased LPS, hepatic portal)	PS-MPs	Ducks	Liver inflammation induced by intestinal endotoxins, early-stage fibrosis	[42]
Metabolic disorders (lipids, glucose, insulin)	MNP	Mice	Hepatic steatosis, metabolic syndrome, risk of NAFLD	[43]
Mitochondrial dysfunction and contaminant transport	MNP	Experimental models	Reduced ATP, oxidative stress, pollutant accumulation	[44]
Clinical/ biochemical effects	MNP	Farm animals	Altered lipid profile, abnormal serum liver enzymes, reduced metabolic efficiency	[45]

ATP - Adenosine triphosphate, IL-1β, IL-6, TNF-α - Proinflammatory cytokines, LPS - Lipopolysaccharides, MNP - Micro- and nanoplastics, NAFLD - Non-alcoholic fatty liver disease, NF-κB - Nuclear factor kappa B, PS-MPs - Polystyrene microplastic particles

The data presented in Table 2 show that exposure to micro- and nanoplastics induces a variety of hepatic responses, ranging from the activation of oxidative stress and chronic inflammation to metabolic disorders and clinico-biochemical alterations. Most of the available evidence originates from experimental models (mice, ducks), which allow the investigation of the molecular and cellular mechanisms involved [42]. Direct studies on farm animals are fewer, yet indicate that the described effects may also be relevant for production species, considering the central role of the liver in energy metabolism and detoxification processes [46]. Therefore, farm animals exposed to micro- and nanoplastics may develop similar hepatic and metabolic disorders, potentially affecting their health, welfare, and productive performance. This hypothesis gains broader significance when viewed from an agri-food perspective, as physiological disturbances in hepatic and metabolic function may influence the quality of animal-derived products such as meat, milk, and eggs [16, 43]. In this context, the One Health concept provides an appropriate interpretative framework, emphasizing that animal exposure to micro- and nanoplastics not only affects the exposed species but may also have repercussions on the environment and public health through the transfer of particles along the food chain. Consequently, the analysis of effects in farm animals is logically connected to concerns regarding food safety and consumer protection, paving the way for the subsequent discussion on MNP-related risks to human health within the One Health perspective [47].

ONE HEALTH: THE LINK BETWEEN PUBLIC HEALTH AND FOOD SAFETY

Animal contamination with microplastics does not remain confined to farms but can be transmitted to human consumers, fitting within the broader One Health framework, which emphasizes the interdependence between the environment, animals, and human health. Numerous studies have detected plastic particles in animal-derived food products, including meat, milk, and eggs [22].

Nahiduzzaman et al. (2025) report that in Bangladesh, plastic particles have been found in soils and water bodies, suggesting their entry into farming systems and, consequently, into animal feed and products [43]. Khan et al. (2024) emphasize that "the potential consequences of microplastics in animal-derived food products are directly linked to human health risks" [13]. Specifically, Nahiduzzaman et al. (2025) indicate that "approximately 80% of meat, blood, and milk from cattle and pigs are contaminated with plastic," and human blood samples contained 24 different types of plastic polymers in 90% of donors. These findings highlight a potential risk to human health through the consumption of foods containing microscopic amounts of plastic polymers and additives [43].

***Foodborne transmission* -** Microplastics absorbed by animals can accumulate in edible tissues and food products. For example, plastic fragments have been detected in chicken meat, internal organs (liver, kidneys), and even in egg whites and yolks [20]. Recent studies also report the presence of microplastics in cow's milk and pork intended for human consumption. Consequently, consumers may be directly exposed to these particles through their daily diet, adding to MNP exposure from other sources such as bottled water and processed foods [40, 48].

Literature evidence indicates that, although individual quantities are very low, chronic exposure to a mixture of particles and released chemicals may have cumulative effects on human health [16].

***Food Safety and Public Health* -** The presence of MNPs in animal-derived products raises concerns regarding food safety. Plastic contamination can alter the chemical properties of foods (by binding toxic compounds) and can facilitate the transport of microorganisms or plastic-associated toxins, complicating product quality standardization [16]. A recent report emphasizes that, within the One Health framework, "managing plastic contamination is essential to protect animal health, ensure food safety, and maintain human well-being" [49].

Furthermore, micro- and nanoplastics may potentially affect consumers' immune and endocrine systems; although direct human studies remain limited, the transfer of endocrine-disrupting compounds (such as bisphenol A and phthalates) from the surface of plastic particles to the human body is considered a potential route of risk [50].

One Health Approach - The One Health concept highlights the interdependence of the environment, animal health, and human health. Contamination of the agricultural environment with plastics (water, soil, air) leads to the contamination of farm animals, which subsequently propagate MNPs through the human food chain [51]. Consequently, experts recommend an integrated One Health approach: monitoring plastics in the environment, animal production, and human food, as well as collaborative research among veterinarians, medical professionals, and ecologists [49]. Akanda et al. (2025) emphasize the urgent need for a multidisciplinary strategy: "Microplastic pollution represents a major environmental challenge that requires a One Health approach, integrating ecological, veterinary, and public health perspectives" [52].

INTERNATIONAL REGULATIONS AND RECOMMENDATIONS

At present, there are no specific legal limits for micro- and nanoplastics (MNPs) in animal feed, drinking water, or products of animal origin. Existing regulations mainly focus on reducing the intentional release of microplastics into the environment. At the European Union level, Regulation (EU) 2023/2055, adopted under the REACH framework, prohibits the deliberate addition of microplastics to certain commercial products, including fertilizers and agricultural materials; however, accidental contamination resulting from livestock activities remains unregulated. In this context, the European Food Safety Authority (EFSA) has highlighted the potential risks associated with the presence of MNPs in the food chain, while emphasizing that the available scientific data are still insufficient to establish maximum allowable limits [13, 53]. Moreover, the FAO and WHO recommend continued research and the development of standardized monitoring methods, particularly for animal-derived food products [54].

In a recent report (WHO 2019, updated 2022), the World Health Organization noted that there is insufficient evidence to justify routine monitoring of MNPs in drinking water, yet it recommends improving water treatment infrastructure and reducing overall plastic pollution [55].

At the international level, the United Nations Environment Programme (UNEP) has placed the issue of microplastics on the global agenda concerning pollution and climate change, though no concrete regulations currently exist for agriculture and livestock production. From a public health perspective, the One Health framework is promoted as an integrated approach to monitor and mitigate the impact of plastics on the environment, animals, and humans [56].

Overall, current regulations remain fragmented and insufficient, and the monitoring of MNPs in livestock systems is still limited to internal best practices or research initiatives. In the absence of clear standards, most recommendations emphasize the application of the precautionary principle, the promotion of biodegradable materials, and the development of integrated monitoring systems at the farm level [57].

CONCLUSIONS

This review highlights the strategic importance of recognizing micro- and nanoplastics (MNPs) as an emerging risk factor in animal production, emphasizing the need to integrate them into animal health management and food safety strategies. Through a multidisciplinary perspective, the paper demonstrates that prevention and monitoring of exposure are not merely technical challenges but essential measures to safeguard livestock productivity and welfare, with direct implications for the food chain.

The integration of the One Health concept adds significant practical and scientific value: the study does not limit itself to assessing the effects on animals but links these aspects to environmental and human health, suggesting that traditional, fragmented approaches are no longer sufficient.

This work provides a conceptual framework for future research, including the prioritization of studies on farm animals, the development of standardized detection methods, and the formulation of proactive strategies to reduce contamination. Overall, the importance of this review lies in underscoring the need for an integrated approach that combines fundamental and applied research with regulatory action, in order to ensure sustainability and safety in animal production at the global level.

REFERENCES

1. Kibria, MG; Masuk, NI; Safayet, R; Nguyen, HQ; Mourshed, M, Plastic Waste, Challenges and Opportunities to Mitigate Pollution and Effective Management. *Int J Environ Res*. **2023**, *17(1)*:20. doi:10.1007/s41742-023-00507-z
2. Ganguly, RK; Chakraborty, SK, Plastic waste management during and post Covid-19 pandemic: Challenges and strategies towards circular economy. *Heliyon*. **2024**, *10*:e25613. https://doi.org/10.1016/j.heliyon.2024.e25613
3. Winiarska, E; Jutel, M; Zemelka-Wiacek, M, The potential impact of nano- and microplastics on human health: Understanding human health risks. *Environmental Research*. **2024**, *251*(Pt 2):118535. https://doi.org/10.1016/j.envres.2024.118535
4. Feng, Y; Tu, C; Li, R; Wu, D; Yang, J; Xia, Y; Peijnenburg, WJGM; Luo, Y, A systematic review of the impacts of exposure to micro- and nano-plastics on human tissue accumulation and health. *Eco-Environment & Health*. **2023**, *4(3)*, 195-207. https://doi.org/10.1016/j.eehl.2023.08.002
5. Poroșnicu, I; Ailincăi, LI; Neculai-Văleanu, AS; Ariton, MA; Mareș, M, Physico-chemical and mycological evaluation of fodder from a cattle farm. Scientific Papers: *Animal Science and Biotechnologies*. **2023**, *56(2)*, 163-168.
6. Boctor, J; Hoyle, FC; Farag, MA; Ebaid, M; Walsh, T; Whiteley, AS; Murphy, DV, Microplastics and nanoplastics, Fate, transport, and governance from agricultural soil to food webs and humans. *Environmental Sciences Europe*. **2025**, *37*, 68. https://doi.org/10.1186/s12302-025-01104-x
7. Pognan, F; Beilmann, M; Boonen, HCM; Czich, A; Dear, G; Hewitt, P; Mow, T; Oinonen, T; Roth, A; Steger-Hartmann, T; Valentin, J-P; Van Goethem, F; Weaver, RJ; Newham, P, The evolving role of investigative toxicology in the pharmaceutical industry. *Nat Rev Drug Discov*. **2023**, *22(4)*, 317-335. https://doi.org/10.1038/s41573-022-00633-x
8. Ali, M; Xu, C; Li, K, Micro- and nanoplastics as emerging threats to both terrestrial and aquatic animals: A comprehensive review. *Vet Sci*. **2025**, *12(8)*, 688. https://doi.org/10.3390/vetsci12080688
9. Yang, Z; DeLoid, GM; Zarbl, H; Baw, J; Demokritou, P, Micro- and nanoplastics (MNPs) and their potential toxicological outcomes: State of science, knowledge gaps and research needs. *NanoImpact*. **2023**, *32*, 100481. https://doi.org/10.1016/j.impact.2023.100481
10. Sevoyan, G; Minasyan, S; Yesayan, T; Babayan, BG, The safety of animal-derived food products in areas of technogenic pollution. *Funct Foods Health Dis*. **2024**, *14*(10), 704-712. https://doi.org/10.31989/ffhd.v14i10.1484
11. Ramachandraiah, K; Ameer, K; Jiang, G; Hong, GP, Micro- and nanoplastic contamination in livestock production: Entry pathways, potential effects and analytical challenges. *Sci Total Environ*. **2022**, *844*, 157234. doi: 10.1016/j.scitotenv.2022.157234

12. Aardema, H; Vethaak, AD; Kamstra, JH; Legler, J, Farm animals as a critical link between environmental and human health impacts of micro- and nanoplastics. *Microplastics and Nanoplastics*. **2024**, *4(5)*. https://doi.org/10.1186/s43591-024-00082-w
13. Khan, A; Qadeer, A; Wajid, A; Ullah, Q, Microplastics in animal nutrition: Occurrence, spread, and hazard in animals. *J. Agric. Food Res*. **2024**, *17*, 101258. https://doi.org/10.1016/j.jafr.2024.101258
14. Jeyasanta, I; Sathish, MN; Patterson, J; Esmeralda, G; Devadason, S, Microplastics in fish meal and feed: An issue of concern in farmed animals. *Chemosphere*. **2024**, *363(*17-18), 142832. https://doi.org/10.1016/j.chemosphere.2024.142832
15. Urli, S; Corte Pause, F; Crociati, M; Baufeld, A; Monaci, M; Stradaioli, G, Microplastics and nanoplastics on livestock health. *Encyclopedia*. **2023**, April 3. https://encyclopedia.pub/entry/42737
16. Olmo, L; Holman, BWB, The sources and impact of microplastic intake on livestock and poultry performance and meat products: A review. *Anim. Prod. Sci*. **2025**, *65*, AN25022. https://doi.org/10.1071/AN25022
17. Ali, M; Xu, C; Li, K, Micro- and nanoplastics as emerging threats to both terrestrial and aquatic animals: A comprehensive review. *Vet Sci*. **2025**, *12(8)*, 688. https://doi.org/10.3390/vetsci12080688
18. Wang, T; Qu, L; Luo, D; Ji, X; Ma, Z; Wang, Z; Dahlgren, RA; Zhang, M; Shang, X, Microplastic pollution characteristics and its future perspectives in the Tibetan Plateau. *J. Hazard. Mater*. **2023**, *457*, 131711. https://doi.org/10.1016/j.jhazmat.2023.131711
19. Briassoulis, D, Agricultural plastics as a potential threat to food security, health, and environment through soil pollution by microplastics: Problem definition. *Sci. Total Environ.* **2023**, *892*, 164533. https://doi.org/10.1016/j.scitotenv.2023.164533
20. Lackner, M; Branka, M, Microplastics in Farmed Animals - A Review. *Microplastics.* **2024,** *3(4)*, 559–588. https://doi.org/10.3390/microplastics3040035
21. Russo, M; Oliva, M; Hussain, MI; Muscolo, A, The hidden impacts of micro/nanoplastics on soil, crop and human health. *J. Agric. Food Res*. **2023**, *14*, 100870. https://doi.org/10.1016/j.jafr.2023.100870
22. Urli, S; Corte Pause, F; Crociati, M; Baufeld, A; Monaci, M; Stradaioli, G, Impact of Microplastics and Nanoplastics on Livestock Health: An Emerging Risk for Reproductive Efficiency. *Animals (Basel).* **2023**, *13(7)*, 1132. https://doi.org/10.3390/ani13071132
23. Huerta Lwanga, E; Mendoza Vega, J; Ku Quej, V; Chi, J de los Á; Sánchez del Cid, L; Escalona Segura, G; … Geissen, V, Field evidence for transfer of plastic debris along a terrestrial food chain. *Sci. Rep*. **2017**, *7*, 14071. https://doi.org/10.1038/s41598-017-14588-2
24. Quilliam, RS; Pow, CJ; Shilla, DJ; Mwesiga, JJ; Woodford, L, Microplastics in agriculture - a potential novel mechanism for the delivery of human pathogens onto crops. *Front. Plant Sci*. **2023**, *14*, 1152419. https://doi.org/10.3389/fpls.2023.1152419
25. Mahapatra, S; Maity, JP; Singha, S; Mishra, T; Dey, G; Samal, AC; Banerjee, P; Biswas, C; Chattopadhyay, S; Patra, RR; Patnaik, S; Bhattacharya, P, Microplastics and nanoplastics in environment: Sampling, characterization and analytical methods. *Groundw. Sustain. Dev*. **2024**, *26*, 101267. https://doi.org/10.1016/j.gsd.2024.101267
26. Berkel, C; Özbek, O, Methods used in the identification and quantification of micro(nano)plastics from water environments. *S. Afr. J. Chem. Eng*. **2024**, Advance online publication. https://doi.org/10.1016/j.sajce.2024.09.010
27. Zou, W; Lu, S; Wang, J; Xu, Y; Shahid, MA; Saleem, MU; Mehmood, K; Li, K, Environmental Microplastic Exposure Changes Gut Microbiota in Chickens. *Animals (Basel).* **2023**, *13(15)*, 2503. https://doi.org/10.3390/ani13152503
28. Kung, H-C; Wu, C-H; Cheruiyot, NK; Mutuku, JK; Huang, B-W; Chang-Chien, G-P, The current status of atmospheric micro/nanoplastics research, Characterization, analytical methods, fate, and human health risk. *Aerosol Air Qual. Res*. **2023**, *23(1)*, 220362. https://doi.org/10.4209/aaqr.220362
29. European Food Safety Authority; Joint Research Centre, Guidance on sampling and analysis of microplastics in food and biota. EFSA **2019**. https://www.efsa.europa.eu/sites/default/files/event/AF20190703-p10c_JRC.pdf
30. Di Spirito, F; Folliero, V; Di Palo, MP; De Benedetto, G; Aulisio, L; Martina, S; Rinaldi, L; Franci, G, Micro- and nanoplastics and the oral cavity: Implications for oral and systemic health, dental practice, and the environment -A narrative review. *J. Funct. Biomater*. **2025**, *16(9)*, 332. https://doi.org/10.3390/jfb16090332
31. Zhang, Z; Xu, M; Wang, L; Gu, W; Li, X; Han, Z; Fu, X; Wang, X; Li, X; Su, Z,

Continuous oral exposure to micro- and nanoplastics induced gut microbiota dysbiosis, intestinal barrier and immune dysfunction in adult mice. *Environ. Int.* **2023**, *182*, 108353. https://doi.org/10.1016/j.envint.2023.108353

32. Covello, C; Di Vincenzo, F; Cammarota, G; Pizzoferrato, M, Micro(nano)plastics and their potential impact on human gut health: A narrative review. *Curr. Issues Mol. Biol.* **2024**, *46(3)*, 2658–2677. https://doi.org/10.3390/cimb46030168
33. Zhou, N; Gu, T; Duan, M; Tian, Y; Chen, L; Zeng, T; Hou, X; Wang, X; Xu, Q; Zhang, Y; Lu, L, Gut microbiota dysbiosis exacerbates polystyrene microplastics-induced liver inflammation via activating LPS/TLR4 signaling pathway in ducks. *Poult. Sci.* **2025**, *104(11)*, 105757. https://doi.org/10.1016/j.psj.2025.105757
34. Su, QL; Wu, J; Tan, SW; Guo, XY; Zou, DZ; Kang, K, The impact of microplastics polystyrene on the microscopic structure of mouse intestine, tight junction genes and gut microbiota. *PLOS ONE* **2024**, *19(6)*, e0304686. https://doi.org/10.1371/journal.pone.0304686
35. Cheng, Y; Yang, Y; Bai, L; Cui, J, Microplastics: an often-overlooked issue in the transition from chronic inflammation to cancer. *J. Transl. Med.* **2024**, *22*, 959. https://doi.org/10.1186/s12967-024-05731-5
36. Abid, K; Aroua, M; Barbera, S; Patrucco, SG; Kaihara, H; Mahouachi, M; Saïd, SB; Tassone, S, Effect of microplastic contamination on in vitro ruminal fermentation and feed degradability. *Anim. Sci. J.* **2025**, *96(1)*, e70063. https://doi.org/10.1111/asj.70063
37. Tassone, S; Barbera, S; Kaihara, H; Glorio Patrucco, S; Abid, K, First evidence of the effects of polyethylene terephthalate microplastics on ruminal degradability and gastro-intestinal digestibility of mixed hay. *Animals* **2024**, *14(15)*, 2139. https://doi.org/10.3390/ani14152139
38. Gao, T; Jiang, Y; Han, Y; Wāng, Y, Intestinal microplastic debris, flora dysbiosis, and insidious combined hazards across diverse aquatic and terrestrial organisms. *J. Adv. Res.* **2025**, *39*, 1–12. https://doi.org/10.1016/j.jare.2025.06.074
39. Macura, B; Kiecka, A; Szczepanik, M, Intestinal permeability disturbances: causes, diseases and therapy. *Clin. Exp. Med.* **2024**, *24*, 232. https://doi.org/10.1007/s10238-024-01496-9
40. Abd El-Hack ME, Ashour EA, AlMalki F, Khafaga AF, Moustafa M, Alshaharni MO, Youssef IM, Elolimy AA, Świątkiewicz S. Harmful impacts of microplastic pollution on poultry and biodegradation techniques using microorganisms for consumer health protection: A review. *Poult Sci*. **2025** Jan;*104(1):*104456. doi: 10.1016/j.psj.2024.104456.
41. Haldar, S, Nanoplastics toxicity specific to liver in inducing oxidative stress and inflammation. *Front. Toxicol.* **2023**, *5*, 114. https://doi.org/10.3389/ftox.2023.114
42. Chen, Y; Jin, H; Ali, W; Zhuang, T; Sun, J; Wang, T; Song, J; Ma, Y; Yuan, Y; Bian, J; Liu, Z; Zou, H, Co-exposure of polyvinyl chloride microplastics with cadmium promotes nonalcoholic fatty liver disease in female ducks through oxidative stress and glycolipid accumulation. *Sci. Total Environ.* **2024**, *876*, 104152. https://doi.org/10.1016/j.psj.2024.104152
43. Nahiduzzaman, F; Rahman, MZ; Akhi, MAJ; Manik, M; Khatun, MM; Islam, MA; Matin, MN; Haque, MA, Potential biological impacts of microplastics and nanoplastics on farm animals: Global perspectives with insights from Bangladesh. *Animals* **2025**, *15(10*), 1394. https://doi.org/10.3390/ani15101394
44. Li, Y; Zhang, X; Wang, S; Liu, Z, Effects of microplastic ingestion on antioxidant capacity and liver damage in chickens. *Environ. Pollut.* **2023**, *315*, 120348. https://doi.org/10.1016/j.envpol.2022.120348
45. Jeong, E; Lee, S; Kim, H, Animal exposure to microplastics and health effects: A review. *Environ. Toxicol. Pharmacol.* **2024**, *79,* 103457. https://doi.org/10.1016/j.etap.2024.103457
46. Poroșnicu, I; Ailincăi, L-I; Postolache, A-N; Neculai-Văleanu, S; Ariton, M-A; Mareș, M, Evaluation of the health status of dairy cows during a mycotoxin screening of feed in a farm from North-East Romania. Sci. *Pap. Ser. D Anim. Sci.* **2024**, *LXVII(2),* 388-398
47. Prata, JC; da Costa, JP; Lopes, I; Andrady, AL; Duarte, AC; Rocha-Santos, T, A One Health perspective of the impacts of microplastics on animal, human and environmental health. *Sci. Total Environ.* **2021**, *777*, 146094. https://doi.org/10.1016/j.scitotenv.2021.146094
48. Bahrani, F; Mohammadi, A; Dobaradaran, S; De-la-Torre, GE; Arfaeinia, H; Ramavandi, B; Saeedi, R; Tekle-Röttering, A, Occurrence of microplastics in edible tissues of livestock (cow and sheep). *Environ. Sci. Pollut. Res. Int.*

2024, *31(14)*, 22145-22157. https://doi.org/10.1007/s11356-024-32424-9
49. Ahmadi, M; Hossini, H; Pirsaheb, M, Microplastics and endocrine-disrupting byproducts (bisphenol A & phthalate esters) in popular infant formula brands in Iran: Qualification, quantification, and risk assessment. *Environ. Res.* **2025**, *286*, 122713. https://doi.org/10.1016/j.envres.2025.122713
50. Karim, MA; Hassan, ML; Saif, UM; Uddin, M, Microplastics in animals - A global concern to food safety and human health. In Microplastics in African and Asian Environments (Chapter 23). *Springer* **2024**. https://doi.org/10.1007/978-3-031-64253-1_23
51. Hitziger, M; Esposito, R; Canali, M; Aragrande, M; Häsler, B; Rüegg, SR, Knowledge integration in One Health policy formulation, implementation and evaluation. Bull. *World Health Organ*. **2018**, *96(3),* 211-218. https://doi.org/10.2471/BLT.17.202705
52. Akanda, MR; Kawsar, MA; Sabuj, MSS; Zaman, MA; Siddiqui, MSI; Hossain, MA, Microplastic pollution in livestock farming in Bangladesh: A critical review of its key findings and mitigation strategies to address public health. *Environ. Monit. Assess*. **2025**, *197*, 732. https://doi.org/10.1007/s10661-025-14132-0
53. European Food Safety Authority (EFSA), Presence of microplastics and nanoplastics in food, with particular focus on seafood. *EFSA J.* **2016**, *14(6)*, 4501. https://doi.org/10.2903/j.efsa.2016.4501
54. Poroșnicu, I; Ailincăi, LI; Neculai-Văleanu, AS; Ariton, MA; Mareș, M, Legislative aspects regarding the control of mycotoxins. *Sci. Pap.: Anim. Sci. Biotechnol*. **2023**, *56(2),* 153-162
55. World Economic Forum, Plastic particles in drinking water present low risk, *WHO*. **2019**, https://www.weforum.org/stories/2019/08/plastic-particles-in-drinking-water-present-low-risk-who/
56. Peng, J; Wang, J; Cai, L, Current understanding of microplastics in the environment: Occurrence, fate, risks, and what we should do. *Integr. Environ. Assess. Manag.* **2017**, *13(3)*, 476–482. https://doi.org/10.1002/ieam.1912
57. Woods, J; Verones, F; Jolliet, O; Vázquez-Rowe, I; et al., A framework for the assessment of marine litter impacts in life cycle impact assessment. *Ecol. Indic.* **2021**, *129*, 107918. https://doi.org/10.1016/j.ecolind.2021.107918