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Microplastics in animal nutrition: Occurrence, spread, and hazard in animals

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ABSTRACT

Microplastics (MPs) are small plastic particles less than 5 mm in size, which have become a common environmental contaminant, spreading across terrestrial and aquatic ecosystems. Concerns have been raised about the impact of microplastics on animal health and nutrition due to their accumulation and potential transfer through the food chain. This review aims to summarize current knowledge about microplastics in animal nutrition, with a focus on their occurrence, sources, routes of exposure, and potential effects on animal physiology and metabolism. Animals can consume microplastics through a variety of routes, including direct consumption of contaminated food, uptake from contaminated water, and ingestion of organisms that have already consumed microplastics. MPs have been found in a variety of animal species, including fish, birds, mammals, and invertebrates, highlighting the possibility of widespread exposure and bioaccumulation. MPs can interact with the gastrointestinal tract after being ingested, potentially influencing nutrient absorption, gut microbiota composition, and overall digestive efficiency. MPs may also act as carriers for other chemical pollutants, potentially increasing their bioavailability and toxic effects on animals. While some studies indicate that microplastics may cause adverse effects in animals such as inflammation, oxidative stress, and disruption of endocrine functions, the overall health effects and long-term consequences of microplastic (MP) exposure in animal nutrition remain unknown. Furthermore, the review discusses the potential consequences of microplastics in animal-derived food products, considering the human health risks associated with their consumption.

1. Introduction

Plastic pollution is one of the most severe environmental disasters caused by humans, producing millions of tonnes of waste each year [1]. The production and consumption of plastics have progressively increased in the past 5 decades. Because of characteristics such as lightweight, durability, persistency, low cost, and low thermal/electrical conductivity. As a result, plastic has become ubiquitous in our everyday lives and is now present in virtually all ecosystems [2]. China may be the world's largest manufacturer of plastic. Still, the United States is by far the world's largest generator of plastic waste– it produced about 42 million metric tons of the stuff (46 million U.S. tons) in 2016 [3].

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Approximately 50 % of plastic waste collected for recycling in countries worldwide was traded internationally [4]. In many African countries, about 12 % of waste plastics are recycled, and the rest are disposed of, burned, or buried [5]. According to one study, it is reported that China, Indonesia, Philippines, Vietnam, Sri Lanka, Thailand, Malaysia, and India from the Asia Pacific region are ranked among the world's top 20 countries as sources of marine plastic waste. In other words, the Asia-Pacific region is now considered as a hotspot for plastic pollution [6]. Over 1.6 million people are employed in the plastics industry in Europe alone. In 2018, the amount of plastic produced worldwide was close to 360 million tonnes [7]. While this rapid growth has brought convenience, it has also produced significant plastic waste, raising serious environmental concerns. The projections indicate that between 2.5×10^7 to 1.3×10^8 tons of microplastic debris may end up on the ocean's surface by the turn of the century [8].

Based on their size, plastic can be divided into microplastic (>25 mm), mesoplastic (5–25 mm), microplastic (<5 mm), and nano-plastic (<1 μm) [9]. Compared to larger microplastic particles, nanoplastics are considered potentially more dangerous [10]. MPs are constantly decomposing in marine environments due to the physical, chemical, and biological effects. The rate of microplastic decomposition also varies due to some other environmental factors such as temperature, sunlight, depth of water, and the presence of bacteria [11]. MPs pose a significant threat as they can carry various toxic chemicals, increasing their overall toxicity, and can easily penetrate organelles and cell membranes [12]. Collecting and removing these tiny plastic pieces from the environment is extremely challenging. These small particles can travel between numerous habitats and are not limited to one. While it is well known that soil is a major source of MPs, the ocean is also a significant area where accumulation [13].

These plastic products pollute the environment and accumulate in aquatic and terrestrial ecosystems worldwide. Long after the useful life of the original plastic products has passed, these plastic fragments continue to exist in the environment due to their slow rate of decomposition. MPs have thus been found in a variety of living things [14]. Aquatic animals are more likely to consume microplastics directly because of their size and resemblance to zooplankton [15]. Numerous ecotoxicological studies have shown that eating microplastics can cause organ damage, oxidative stress, reproductive problems, general debilitation, and even death in organisms [16]. To address the microplastic pollution in treated water and sewage sludge, the European Parliament proposed regulations in 2019 [17].

Recent research has shown that microplastics can endanger the living world by ingesting them directly or indirectly through trophic transfer [18]. As they interact with terrestrial animals, invertebrates, and some plant pollinators, MPs have negative effects that go beyond aquatic ecosystems [19]. Microplastic pollution on land, specifically in agricultural soils, may be 4–23 times higher than in aquatic environments. Both natural and human-made processes can result in the entry of small MPs particles into the soil [20]. According to some evidence, MPs may interact with other harmful substances, potentially amplifying their negative effects on the environment [21]. However, the ability of MPs to travel great distances, increase bioavailability for animals, and act as reservoirs for various chemicals in the environment depends on the environment as well as the characteristics of the microplastic and the adsorbate chemical [22]. This issue requires additional clarification [23]. The purpose of this review is to give a thorough overview of the most recent research on microplastics in animal nutrition. It focuses on the availability and dispersion of microplastics, their sources, the methods by which animals are exposed to them, as well as any potential effects on animal physiology and metabolism.

2. Classification of microplastics

According to their source, MPs can be divided into primary and secondary types [24]. It has been estimated that secondary MPs represent 70–80 % of MPs released into the environment whereas only 15–31 % are primary MPs [25]. Primary microplastics are purposefully manufactured in small sizes and are released into the environment directly from non-biological sources [25]. These materials come from shipbreaking procedures and air-blasting technology, as well as various plastic fragments, fibers, pellets, seeds, and spheres used in the agriculture, cosmetics, and pharmaceutical industries [26], laundering of synthetic clothes, and wear and tear of tires through driving (as shown in Fig. 1) [27]. Secondary MPs, on the other hand, emerge from the breakdown of large plastic materials, both through non-living processes and the impact of living organisms after exposure to the environment [27]. Origins of secondary microplastic encompass domestic use, industrial production, remnants from discarded automobile tires, and other similar sources (as shown in Fig. 1) [28]. Furthermore, physical characteristics such as density (light or heavy), pliability (hard or soft), and form (fragments, pellets, filaments, and granules) are used to classify microplastics [25]. The configuration and composition of microplastics are closely related to their source materials, with polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), nylon (PA), cellulose acetate (CA), and thermoplastic polyester (PET) being the most common plastic polymers [29].

2.1. *Shapes of MPs*

MPs come in a variety of shapes, sizes, and color sorting systems (SCS), which enables the characterization of these particles based on their visual characteristics, making it easier to classify them [30]. Additional classification of microplastic shapes, such as spheres, cylindrical, disc-shaped, flat, egg-shaped, elongated, and rounded particles, has been suggested by some researchers [31]. The initial form of the material, the length of the degradation processes, and the environmental circumstances in which the material is present are all factors that affect the shape of the microplastic [24].

2.2. *Color of MPs*

Each microplastic particle is given a unique color as part of the SCS, which also takes color into account [30]. Aquatic organisms are significantly impacted by the color of microplastics. While multicolored and black microplastics are less frequently seen, colorless or white microplastics are frequently found in surface seawater samples and sediments. Animals may confuse microplastics for their actual food and ingest them because of the color resemblance between them and natural food sources. For instance, white and transparent plastic fibers are frequently consumed by fish, which introduces microplastics into the food chain and may eventually cause human ingestion [24].

3. The exposure pathways of environmental MPs to animals

MPs can be ingested by animals in a variety of ways, illustrating the widespread nature of microplastic contamination and its potential effect on animal populations. Fig. 2 shows the detailed pathway of MPS intake by animals.

3.1. *MPs exposure from food sources*

It has been discovered that plants can accumulate MPs [32] and that animals that eat contaminated plants can pass MPs on to other animals in the food chain. MPs can be moved from algae to zooplankton and then to fish in aquatic ecosystems through predation relationships [33]. The ocean zooplankton, mollusks, and fish have all been found to contain plastic particles [34]. Marine MPs could potentially be transferred to livestock and poultry raised on feeds made from marine sources (such as fishmeal, seaweed, etc.). Although the transfer of MPs along terrestrial food chains has not been thoroughly investigated, MPs have been discovered in the feces of sheep [35], dairy cows, poultry, and swine

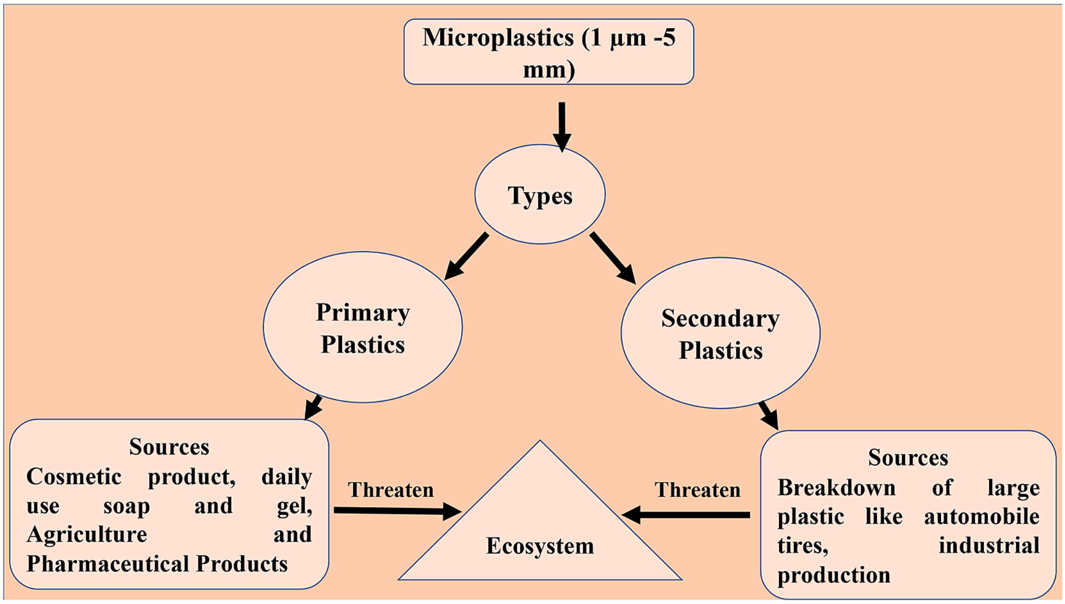

Fig. 1. Schematic presentation of microplastic types, sources, and threats.

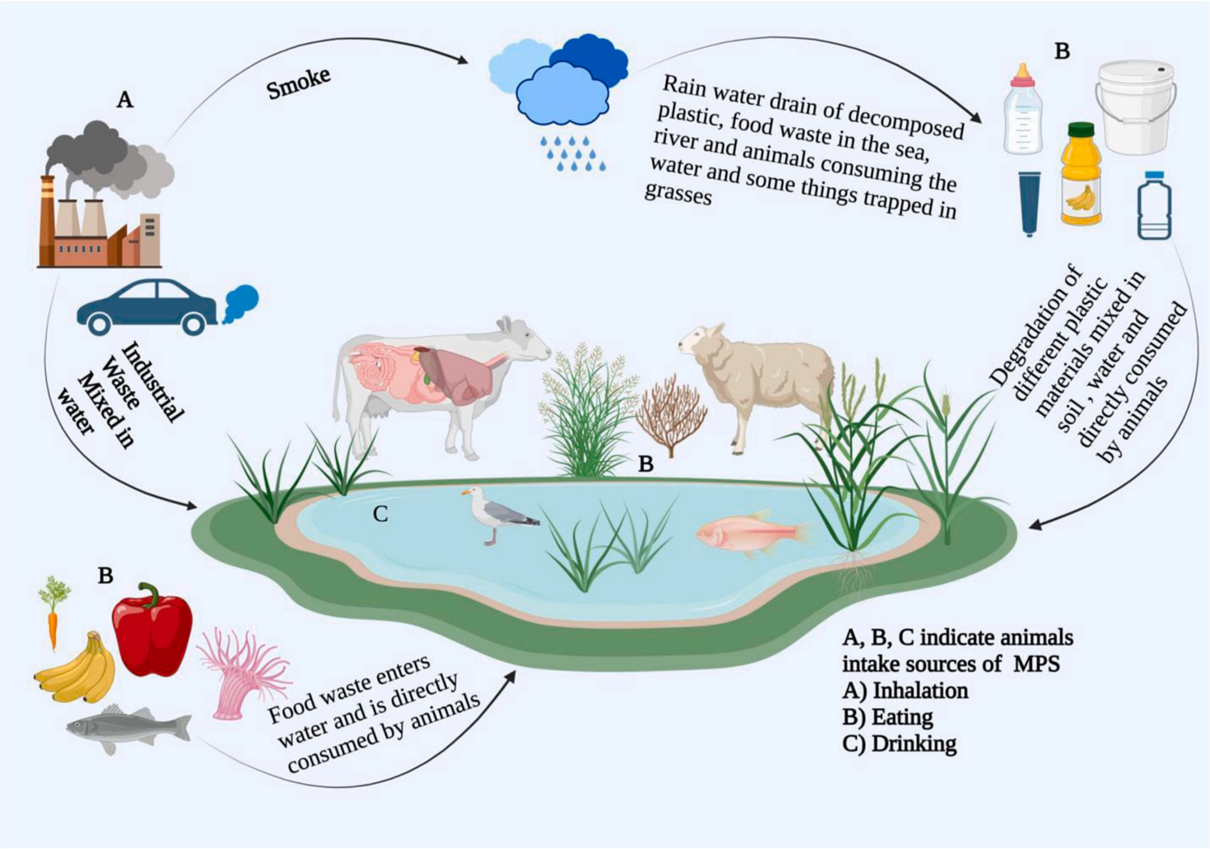

Fig. 2. Schematic pathways of MPs intake by animals.

[36]. These results imply that domestic animals are also subjected to MP exposure and thus acquire MPs in their bodies. Animals that are used for grazing and wildlife may unintentionally consume plastic mulch and waste, allowing MP to enter their bodies [35]. Animal feed processing, shipping, and packaging can all introduce plastic debris. Surface water contamination and inadequate wastewater treatment have been caused by outdated manure management techniques used in livestock and poultry operations [37]. MPs found in animal excrement can be released back into the environment, causing a cycle of contamination in nearby water sources that can then be repeated by animals, feeding the cycle.

3.2. Exposure to MPs from water

The two main ways that livestock animals can be exposed to microplastics (MPs) in their drinking are (1) contaminated surface water and groundwater sources that are used for drinking water and (2) MPs leaching into the drinking water from objects that encounter water, such as water tanks and pipes. Livestock typically get their drinking water from a variety of sources, including well-tapped groundwater, surface water like rivers and lakes, springs, water storage dams, and snow or rain-capture systems [38]. These water sources have been identified as having a high risk of MP contamination, as was previously mentioned [39]. While drinking bottled water or using plastic or paper cups can expose humans to MPs, domestic animals are generally not exposed to bottled water. However, we frequently forget to manage the quality of animal drinking water, which can expose them directly to MP. Livestock may directly encounter MPs in their drinking water because of poor water quality. Even though animals in the livestock industry don't frequently drink bottled water, they frequently use plastic water troughs as water storage. These water troughs are vulnerable to damage from sunlight, heat, and humidity during summer, especially in hot, humid environments [40]. During these processes, MPs found in the water troughs may leach into the drinking water [41]. Due to contamination of the water source or deposition from the surrounding air, MPs may still be present in the water even when alternative materials are used for water troughs. In addition, poorly maintained water troughs may be vulnerable to bacterial contamination from dust and manure as well as bacterial growth [42]. When animals drink the water, the presence of MPs in the water may increase bacterial contamination in water troughs and encourage bacterial adhesion to their surfaces, potentially causing digestive tract inflammation [43].

3.3. *Exposure to MPs from the air*

Airborne MPs are an underappreciated source of contamination that can enter organisms through the mouth or the respiratory system [44]. Terrestrial animals, as opposed to marine ones, are more exposed to and have access to dangers because of airborne MPs. While larger plastic particles are typically expelled through coughing and may be swallowed, entering the digestive tract, inhaled nanoparticles (NPs) are capable of being absorbed and building up in the lungs [45]. When factories or cities produce respirable particles, those particles can travel great distances through the atmosphere and become airborne MPs that animals breathe [46]. Significant amounts of particulate matter are released into the air by agricultural activities, especially livestock production, and these particles can build up if ventilation in livestock housing is inadequate [47]. Domestic animals are significantly more exposed to airborne MPs when the air quality is poor. The sources of airborne MPs in livestock facilities include dust, animal feed, animal manure, aging machinery, and packaging materials. Air has higher oxygen levels and UV intensity than the aquatic environment, which causes plastic products exposed to air to degrade more quickly and release more MPs [48]. Due to the high air temperature and humidity in livestock barns, a variety of microorganisms can exist there as bioaerosol [49]. By the particle concentration, 80 % of these airborne microorganisms stick to the surface of airborne particles [49]. A relatively stable environment for microbial growth is created by the large surface area of MPs, which enables them to form polymers with airborne microorganisms. As a result, the presence of MPs may worsen the level of microbes in the air in livestock barns, increasing the risk of exposure for animals to pathogenic microbes.

4. Translocation of MPs in animals

MPs can enter an animal's body in three different ways (as shown in Fig. 3): 1) through food and water intake, 2) through air inhalation into the lungs, and 3) possibly through the skin surface. According to studies, 39,000 to 52,000 MPs enter the human body every year through food

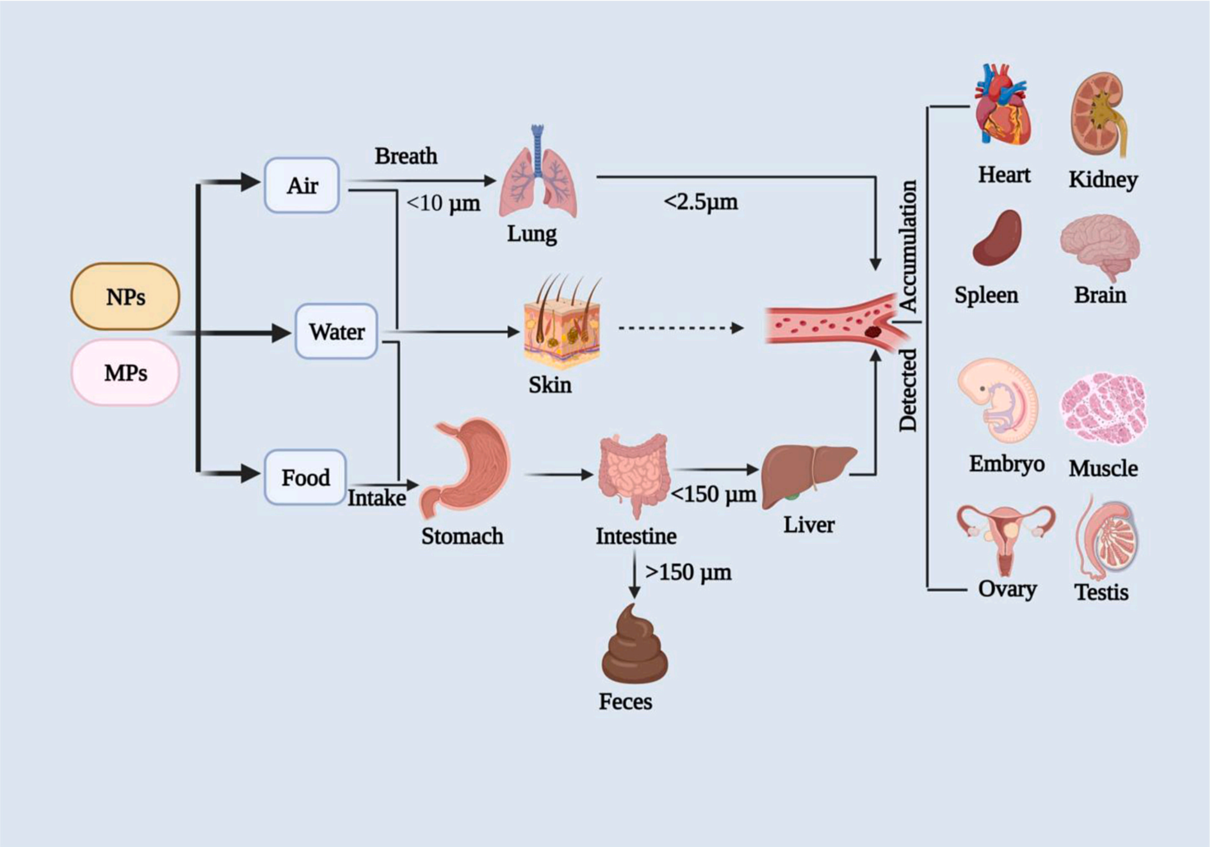

Fig. 3. Schematic representation of NPs and MPs translocation in animals.

and water consumption, and 35,000 to 62,000 MPs are inhaled and then moved on to the digestive system and lungs [39]. Although there is a dearth of information on dermal exposure to MPs, it is generally accepted that there are very few MPs that enter the body through the skin [50].

4.1. *MPs translocate from food and drinking water to the blood circulation system through the digestive tract*

MPs found in food and water can enter the bodies of animals through their mouths. These particles are so small and corrosion-resistant that they can pass through the mouth without being affected by chewing or saliva. MPs can change shape in the stomach by absorbing organic debris such as food particles [51]. It is important to note that the digestive systems of ruminants, which have a specialized compartment known as the rumen, differ from those of monogastric animals. Because the rumen provides a distinct anaerobic environment, the migration and absorption of MPs in ruminant digestive tracts may differ significantly. The presence of rumen microorganisms in this environment suggests that they may be able to degrade or break down MPs [52]. However, few studies specifically address ruminant MP ingestion. As a result, the scope of our review is restricted to the digestion process in monogastric animals.

MPs that enter the stomach are confronted by gastric acid, which contains about 10 % hydrochloric acid. These MPs, on the other hand, have developed a tolerance to acid, making them less affected. The artificial gastric juice did not affect the surface and shape of various MP [51]. Similarly, Park et al. (2020) discovered that gastric juice did not degrade PE-MPs [53]. However, other research suggests that stomach acid may increase the toxicity of these polymers to organisms. Using similar concentrations of hydrochloric acid on PE materials resulted in a rougher surface [54]. A rough surface on plastic particles means a higher surface area to volume ratio, which aids in the adsorption of other substances. Without direct degradation, PE-MPs exposed to artificial gastric fluid gradually degrade into smaller and more stable fragments over time [55]. PS-MPs exhibited surface cracks and more severe cytotoxicity to hepatocytes after treatment with artificial gastric fluid in an in vitro study [56]. The increased toxicity could be attributed to the surface's increased adsorption capacity and the degradation of the –OH group. These findings suggest that gastric acid does not prevent the passage of MPs into the small intestine, but rather increases their toxicity.

These small plastic particles enter the intestinal tract with the chyme after passing through the pylorus. The pH rises to 7.5 in the intestines, and the fluid mixes with digestive juices, including bile. The artificial digestion study found that artificial intestinal fluids did not affect MPs [51]. MPs with a diameter of $<$150 μm can cross the intestinal mucosal barrier via a variety of mechanisms, including (1) endocytosis of enterocytes, (2) transcytosis of M cells, (3) intercellular space when the intestinal barrier is compromised, and (4) the paracellular pathway [57]. MPs cross the intestinal epithelium via different routes depending on their size [53]. Previous research suggested that the accumulation of nanoparticles (NPs) in the intestinal wall may be linked to lymphoid tissue [58]. MPs with diameters greater than $>$150 μm are typically not absorbed by the intestine, but their presence in the intestinal environment can still cause local inflammation and affect intestinal microbes [59]. The impact of these plastic particles on the host is primarily determined by how long they remain in the digestive tract, with slower intestinal peristalsis causing more damage. These larger plastic particles are eventually excreted in the feces. Some MPs that cross the intestine may enter the mesenteric lymphatics and accumulate in lymph nodes, where they are engulfed by immune cells. Approximately 0.3 % of MPs enter the lymph nodes via this route [60]. MPs as large as 50 nm in diameter have been discovered to be transported to lymph nodes in the liver and spleen [61]. The precise mechanism by which MPs are transported through lymphatic vessels and lymph nodes remains unknown. Other polymer particles flow directly through the portal blood to the liver, which can remove molecules and pathogens from circulation [62]. Some MPs are captured by immune cells in the liver, causing local inflammation. Although it has not been proven whether MPs are present in bile, bile may serve as a pathway for MPs to return to the digestive tract. After oral administration of MPs, MPs were found in the blood and various organs of mice [63], indicating that the liver cannot effectively prevent MPs from entering the circulatory system.

4.2. *MPs translocate from air to the blood circulation system through the lungs*

Airborne plastic particles can be directly inhaled into the lungs, unlike MPs found in food and water, which can have long-lasting effects [64]. Some of the inhaled MPs may remain in the lungs even though the mucociliary system helps to capture the majority of them [65]. These imprisoned MPs can be expelled by coughing or sneezing, swallowed and digested, or become lodged in the lungs [66]. Similar to other particles, airborne MPs tend to deposit in the upper airways if they are smaller than 10 μm, and if they are smaller than 2.5 μm, they may enter the deep lungs or even cross the respiratory barrier into the circulation, where they can subsequently accumulate in the lungs [60]. The surface characteristics of MPs are not harmed or changed by the pulmonary environment [60,64,65]. As a result, MPs in the lungs can either leave the lungs and enter the bloodstream, or they can stay there and be removed by immune cells. According to research, particles with shorter edges are more likely to cross the lung blood-air barrier than those with longer ones [65,67]. Recent research has revealed that MPs can accumulate in the lungs, indicating that MPs might reach the lungs through the bloodstream as well as through inhalation [68]. These findings suggest a bidirectional movement of MPs between blood vessels and lung tissue [69].

4.3. *Translocation of MPs through the skin to the subcutaneous tissue*

MPs can penetrate the body through the skin. Although MPs are present in personal care products used as exfoliants for the skin and teeth, dermal exposure to these particles is minimal in animals other than humans [70]. MPs in the air or water used for cooling by spraying may encounter animals in livestock barns. The abundant hair on their bodies, on the other hand, acts as a protective barrier, reducing the impact of MPs on their skin surface. Nanoparticles can enter the skin through two routes: directly through the skin surface via intercellular or transcellular pathways, or indirectly through sweat glands, hair follicles, and wounds [71]. To reach the subcutaneous tissue, MPs must first penetrate the stratum corneum, the skin's outermost layer that allows particles smaller than 100 nm to pass through [34]. The full picture of nanoparticle accumulation, transport, and aggregation is not clear due to the limitation of analytical methods to NPs smaller than 100 nm in vivo and environmental samples. Due to their increased susceptibility to leakage, MPs with surfaces adhered to highly lipophilic organics, such as polycyclic aromatic hydrocarbons, are more likely to penetrate the skin [72]. Furthermore, the stratum corneum does not completely cover the skin's surface, and sweat glands, skin lesions, or hair follicles can all be potential entry points for MPs [73]. These particles can penetrate deep into the hair follicles and reach the deeper layers of the stratum corneum, where they can accumulate or continue to invade the skin [74]. MPs that enter the body through the skin can eventually accumulate in subcutaneous tissues or enter the bloodstream via subcutaneous capillaries. More research on skin exposure to MPs is required in both human and animal studies.

4.4. *MPs accumulate in tissues through blood circulation*

MPs can enter the circulatory system and accumulate in organs such as gut, liver, and kidneys. The smaller MPs can enter the circulatory or lymphatic systems via macrophages [75]. According to studies on human blood, the average concentration of MPs particles in the blood is 1.6 μg/ml, indicating that MPs have entered the circulatory system and are being transported to various tissues throughout the body [45]. In one study it was found that Polystyrene microplastics (PS-MPs) have been found to accumulate in organs such as the heart, spleen, lung, kidney, brain, large intestine, small intestine, uterus, ovary, and blood of exposed mice [76].

5. Potential effects of MPs on animals

MPs have a wide range of potential effects on animals, it is important to note that the extent and severity of these effects can vary depending on factors such as microplastic type, size, and concentration, as well as exposure duration and the species and life stage of the affected animals.

5.1. Effects of MPs on different type of animals

Ruminants such as cattle, sheep, and goats eat plants, but they are unable to digest plant polymers such as cellulose and hemicellulose on their own. Instead, they rely on cellulolytic microorganisms in their gut to break down polymers into substances that other types of bacteria can absorb. Disruptions in the gastrointestinal microflora can harm the digestive system as well as other organs [77]. Ruminal impaction has been observed in livestock animals after ingesting larger plastic items such as bags, bottle caps, and ropes [78]. Ruminal impaction occurs when indigestible plastic materials build up in the rumen, causing indigestion, bloating, and even death [79]. Plastics can also serve as carriers for chemicals that are persistent, bioaccumulative, and toxic (PBT). In numerous studies, persistent organic pollutants (POPs) such as polycyclic aromatic hydrocarbons, polychlorinated biphenyls, organochlorine pesticides, and dioxins have been found to adsorb to microplastics [78].

POPs are still used in some developing countries, although some countries have banned or restricted their use [80]. Depending on the chemical properties of the toxicant, toxic chemical adsorption to microplastics can occur via electrostatic interactions, partitioning, and hydrogen bonding [81]. These chemicals, on the other hand, can desorb or be released from plastics into the surrounding environment, including animal bodies, water, feed, and soil. Toxins released from plastics are influenced by environmental factors such as pH, salinity, and temperature [82]. Toxic chemicals released into the environment as a result of agricultural and industrial activities can cause their persistence and accumulation along the food chain [83]. This biomagnification process results in higher concentrations of contaminants or plastics in organisms at higher trophic levels. While microplastics can also be biomagnified, their specific toxic effects as well as their impact on satiation and nutrition have yet to be thoroughly researched [84]. Some of the various type of plastic and their effect on types of animals are given in Table 1.

According to one study, the crops (a part of the chicken's digestive system) contained only larger plastic particles (MaPs), whereas the gizzards contained both larger (84 % MaPs, >5 mm) and smaller (16 % MPs, 5 mm). In contrast, the feces only contained smaller particles (MPs, 1 mm). This suggests that MaPs are converted into MPs during digestion [85]. The presence of a crop in poultry, which is used to store food, may result in the retention of plastic particles for an extended time [86]. However, an earlier study found that plastic ingestion reduced food consumption and gizzard volume in chickens, indicating that plastic accumulation was harmful to the birds [87]. This can also have an indirect impact on human health because the presence of plastics in gizzards, which are traditionally consumed as food, can be harmful. Plastic ingestion by livestock animals can have two effects: it can directly affect animal health and it can indirectly affect human health through the consumption of livestock-derived food. Plastics used as vectors have been shown to cause biomagnification of certain chemicals in aquatic bird tissues, such as polybrominated diphenyl ethers [88]. MP biomagnification has also been observed in higher trophic-level birds [89]. However, one investigation found no evidence of MPs transporting chemicals. Ingestion of plastics has been linked to decreased feeding, reproductive capacity, and mortality in aquatic birds.

Table 1
Potential effects of particulate plastics on animals.

Spp.	Type of MP	Site	Affects	References
Buffalo	Macroplastics + heavy metals	body fluids and tissues	• Higher concentration of heavy metals in the rumen, blood, liver, muscles, and kidney • Ruminal impaction	[93]
Camel	Macroplastics (polyethylene, polypropylene)	intestines	• Intestinal tract damage • Pathogenic (bacterial) infection • Organ failure	[78]
Hare	Microplastics (PU, PA, PET, PS, PE, PP)	intestines	• Intestinal inflammation • Changes to intestinal mucosa	[90]
Chicken	Plastic pellets (polyethylene)	gizzard	• Increased volume of gizzards • Lowered feeding volume and fitness	[87]
Aquatic birds	Microplastics (polyethylene terephthalate)	stomachs & GI tracts	• Decreased feeding capacity • Lowered reproductive capacity • Mortality	[89]
Aquatic birds	Macroplastics + polybrominated diphenyl ethers (flame retardant)	stomach, adipose tissue	• Biomagnification of toxic chemical	[88]
Terrestrial birds	Microplastics (polyester)	stomachs & GI tracts	• Inflammation • GI Blockage • Cellular necrosis	[86]

There have also been reports of gastrointestinal blockage, internal injury, and a false sense of satiation. Plastic ingestion causes similar negative effects in terrestrial birds, such as gastrointestinal blockage, inflammation, and cellular necrosis. In a hare study, plastic particles were found in the intestines and feces of both free-ranging and indoor control hares [89]. The particles were made of common plastics, and residues of certain chemicals, possibly from agrochemicals, were also found. Intestinal inflammation and mucosal changes were observed, which were linked to environmental contaminants. The study did, however, have sample size limitations [90]. Previous research has linked changes in the intestinal mucosa to diarrhea, weight loss, and death in hares [91]. A rabbit study observed similar toxic effects on the gastrointestinal system, with chemical toxicants such as fungicides, bactericides, solvents, and surfactants identified as the cause [92]. Given that hares and rabbits are members of the same genus, microplastic contaminants may have a similar impact on their health [90].

6. Conclusion

Despite numerous studies on the effects of micro- and nano-plastics on livestock animals, their routes of entry and toxic effects remain unknown. Micro- and nano-plastics are transported and retained through interconnected pathways and sources, including the atmosphere, freshwater, and terrestrial environments. Agricultural practices like plastic mulching have a significant contribution to MNP entry into livestock farming. In intensively farmed poultry, MNP presence is mainly due to the consumption of contaminated feed and water. Plastic consumption is linked to the abundance of and feeding behaviors. MNPs pose direct toxic threats and also act as carriers for chemical toxicants and pathogens, worsening their harmful effects. Microplastic has serious consequences for animal health and welfare, affecting the livestock industry and the production of animal-derived foods. Furthermore, MNPs can have an indirect impact on human health through the consumption of animal-derived food products. Extensive research is required to better understand MNPs' infiltration, distribution, analysis, and toxic effects in livestock. The lack of internationally accepted definitions and standardized sampling and validation methods is a significant limitation. Because of the pervasiveness of MNPs, cross-contamination, and air contamination during sampling and analysis are also major concerns. Long-term studies with larger sample sizes are required to investigate the long-term effects of MNPs on various livestock animals and biological matrices. Improved sampling and analytical methods with higher recovery rates are required, as are improved standardization, comparability, quality assurance, and quality control procedures, as well as rapid and cost-effective protocols. The knowledge gained from this type of research will help to develop plastic waste management strategies that will benefit the livestock industry.

Ethics approval and consent to participate

Experiments on animals were not provided.

Consent for publication

We consent to the publication of the manuscript.

CRediT authorship contribution statement

Aamir Khan: Writing – original draft, Investigation. **Abdul Qadeer:** Writing – original draft, Validation. **Abdul Wajid:** Formal analysis. **Qudrat Ullah:** Writing – original draft. **Sajid Ur Rahman:** Writing – original draft, Conceptualization. **Kaleem Ullah:** Writing – original draft, Visualization. **Sher Zaman Safi:** Visualization, Conceptualization. **Lenka Ticha:** Writing – original draft. **Sylvie Skalickova:** Validation, Supervision. **Pompido Chilala:** Writing – original draft, Validation, Data curation. **Silvie Bernatova:** Validation, Supervision. **Ota Samek:** Validation, Supervision. **Pavel Horky:** Validation, Supervision.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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Abbreviations

Androgen receptors	(ARs)
Bisphenol A	(BPA)
Bisphenol S	(BPS)
Bis(2-ethylhexyl) phthalate	(DEHP)
Cellulose acetate	(CA)
Color sorting system	(SCS)
Cumulus-oocyte complexes	(COCs)
Endocrine-disrupting chemicals	(EDCs)
Hypothalamic-pituitary-gonadal axis	(HPGA)
Luteinizing hormone	(LH)
Larger/macro plastic particles	(MaPs)
Microplastics	(MPs)
Nanoparticles	(NPs)
Nylon	(PA)
Estrogen receptors	(ERs)
Polycystic ovary syndrome	(PCOS)
Persistent organic pollutants	(POPs)
Polyethylene	(PE)
Polypropylene	(PP)
Polystyrene	(PS)
Polyvinyl chloride	(PVC)
Reactive oxygen species	(ROS)
Thermoplastic polyester	(PET)
Ultraviolet	(UV)

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