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Impact of Microplastics on Livestock: Sources, Exposure Pathways, and Physiological Consequences

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Abstract:
Microplastic (MP) contamination has emerged as an escalating environmental hazard with profound implications for terrestrial ecosystems, particularly within livestock-based agricultural systems. The pervasive presence of MPs in soil, water, and feed resources poses significant risks to animal health, food safety, and agricultural sustainability. This review explores the increasing vulnerability of livestock animals to MP exposure, focusing on environmental sources, exposure pathways, and associated physiological impacts. Livestock are regularly exposed to MPs via polluted feed, forage, drinking water, and soils altered with sewage sludge. MP intake, retention, and systemic distribution are influenced by species-specific changes in digestive physiology, notably those between ruminants and monogastric animals. Once internalized, MPs may cause gastrointestinal damage, oxidative stress, immunological dysfunction, hepatic impairment, and possible reproductive harm. Furthermore, microplastics (MPs) act as vectors for hazardous co-contaminants, including heavy metals and persistent organic pollutants, thereby enhancing the risk of bioaccumulation in edible tissues and posing significant challenges to food safety. Chronic exposure to MPs may impair animal health, productivity, and reproductive function, providing greater problems to livestock sustainability, economic viability, and human health. This review highlights the critical need for interdisciplinary research that combines veterinary toxicology, environmental science, and food safety to understand MP toxicokinetics in cattle better and influence evidence-based risk reduction and regulatory regimes.

Keywords: Animal health, environmental contaminants, livestock exposure, and microplastics

1. **Introduction:**

Plastics are widely used in many industries, including consumer items, electrical appliances, autos, agriculture, construction, and manufacturing. Global plastic output has increased, reaching around 350 million tonnes per year (Bucknall, 2020). Microplastics (MPs), defined as plastic particles less than 5 mm in diameter, have become a significant environmental concern due to widespread plastic consumption. Based on their origin, MPs are generally categorized into two main types (Chia et al., 2022). Primary microplastics are intentionally manufactured for specific applications, including microbeads used in cosmetics, microfibers released from synthetic textiles, and plastic resin pellets employed in industrial processes (Yurtsever, 2019; Kim et al., 2023; Chia et al., 2024).

2. In contrast, secondary microplastics result from the degradation of larger plastic debris—such as bottles, bags, and packaging materials—through environmental processes like ultraviolet radiation, thermal exposure, and mechanical wear (Auta et al., 2017; Cha et al., 2023). Microplastics come in a variety of forms and

morphologies, including microbeads, fibres, fragments, and thin films. Their tiny size and low density enable them to readily disseminate via air, water, and soil, resulting in broad pollution of terrestrial and aquatic ecosystems (Ryu et al., 2021; Lee & Cha, 2023). As a result, MPs are now recognized as common environmental contaminants with serious consequences for ecological health and food safety.

There is no part of the natural ecosystem that microplastics (MPs) do not contaminate. MPs affect systems in the air, water, and on land. Microplastics pose a threat to many marine creatures, including plankton and big vertebrates (Auta et al., 2017; Hollerova et al., 2021). Many aquatic animals, such as sea turtles, invertebrates, and fish, contain MPs in their digestive systems (Naidu et al., 2018; Choy et al., 2019). Ingesting microplastics (MPs) in water may obstruct the digestive tracts of suspension feeders like shellfish, plankton, and algae, which can hinder their ability to absorb nutrients and allow adsorbed toxicants to move through aquatic food webs. More and more evidence of MPs is being documented in terrestrial ecosystems, especially in agricultural soils, in addition to aquatic systems (Sarker et al., 2020). Soil fertility, agricultural production, and food supply might be compromised if these particles were to collect in farmlands due to sewage sludge application, plastic mulch degradation, and air fallout (Chia et al., 2021; Cha et al., 2023). According to Huerta Lwanga et al. (2016), invertebrates that live in soil, such as earthworms and springtails, may swallow MPs, which can have adverse effects on their health and change how soil ecosystems work. Airborne particles may deposit even in isolated or virgin places, such as arctic habitats and mountainous terrain, according to recent research (Martina & Castelli, 2023). The discovery of MPs in several human commodities, such as water, shellfish, table salt, and even inhaled air, has prompted concerns about human exposure to these contaminants (Senathirajah et al., 2021). Microparticles (MPs) have a high surface energy and a big surface area-to-volume ratio, which makes them great at adsorbing and concentrating pollutants from the environment (Okoye et al., 2022; Xiang et al., 2022). They are very dangerous to people and the environment because they may carry hazardous compounds, which makes them much more toxic to living things.

Microplastic (MP) exposure in animals raises serious ecological, environmental, and public health issues. MP ingestion may upset food webs, especially when filter feeders like plankton are impacted at the base of the marine environment. Both aquatic and terrestrial species are essential to the stability of ecosystems (Desforges et al., 2015; Tuuri & Leterme, 2023). via trophic transmission, MPs have been shown to bioaccumulate, exposing humans and higher predators to larger amounts via seafood and animal products (Lohmann, 2017; Ebrahimi et al., 2022). MP pollution may increase the hazards for vulnerable and endangered species, making already strenuous conservation efforts even more difficult (Reid et al., 2019). Policies regarding the use of plastics and waste management must be informed by an understanding of the biological and ecological impacts of MPs, which is essential to the discipline of ecotoxicology. The creation of regulatory actions aiming at reducing plastic pollution and safeguarding biodiversity is supported by research showing that MP harms species. Public consciousness of plastic pollution and its ecological ramifications has significantly increased in recent years (Horton, 2022). Ongoing study on microplastic (MP) exposure in animals, especially cattle, is crucial in highlighting the possible hazards to agricultural systems and food safety. Examining MP-livestock interactions improves our comprehension of the complex connections among animal health, environmental pollution, and food chain integrity (Zhang et al., 2023). This multidisciplinary study, combining veterinary science, ecology, and environmental chemistry, has the potential to foster creative mitigation measures and sustainable livestock management practices. Investigating the long-term consequences of microplastics on livestock is crucial for forecasting their influence on animal productivity, reproduction, and food quality. This information may enhance the conservation of genetic resources, direct adaptive farm management, and facilitate the formulation of evidence-based policies to mitigate plastic waste and minimize exposure concerns in agri-food systems.

2. Exposure Sources:

The widespread contamination of aquatic and terrestrial food webs by microplastics (MPs) is becoming more and more apparent. Their metamorphosis from prey to predator poses serious ecological problems that threaten ecosystem stability, food security, and biodiversity (Lusher et al., 2013). From zooplankton to apex predators like sharks, MP consumption has been extensively documented in marine organisms (Gunaalan et al., 2023; Rochman et al., 2015). More than half of the invertebrate species collected from the Galápagos Islands had MPs, and 25% of the fish samples sold in California's markets had them as well (Jones et al., 2021). In a similar vein, carnivorous marine species bought from coastal markets in Ecuador have significant concentrations of MP (Alfaro-Núñez et al., 2021).

Furthermore, terrestrial creatures such as insects, molluscs, rodents, birds, and mammals that inhabit areas near pollution, including abandoned e-waste recycling sites, have also been shown to have MPs (Zheng et al., 2022). It is worth mentioning that MPs have been found in the intestines and waste of animals, including pigs, cows, and chickens, suggesting that they were exposed to them via their food, water, or soil. Proof of microplastic contamination in Antarctic penguins (Bessa et al., 2019), Arctic foxes (Hallanger et al., 2022), and flesh-footed shearwaters (Rivers-Auty et al., 2023) contributes to a growing body of studies demonstrating the global and trophic spread of this environmental issue. The mounting data shows that MPs contaminate creatures at all trophic levels, including those that people eat. It also shows how critical it is to monitor and reduce MP exposure in food production systems, especially in cattle. The presented table highlights the widespread and species-specific impacts of microplastics (MPs) across aquatic and terrestrial animals. Exposure to various polymers—such as polystyrene (PS), polyethene (PE), polypropylene (PP), and others—has been linked to physiological, behavioural, and histological disruptions. These include oxidative stress, organ damage, reproductive impairments, and altered feeding or social behaviours in species ranging from mussels and fish to rodents and invertebrates. Such findings highlight the urgency for targeted ecotoxicological studies and regulatory interventions (Table 1).

Table 1. The effects of microplastic exposure on Aquatic, Terrestrial Species.

Scientific Name	Common Name	Microplastics	Effects	References
Achatina fulica	Giant African snail	PET fibres (average 76.3 µm)	GI wall damage, reduced feeding/excretion, stress	Song et al. 2019
Ardenna carnies	Flesh-footed shearwater	–	Tissue damage, inflammation, fibrosis, organ loss	Rivers-Auty et al. (2023).
Ardenna carneipes	Flesh-footed shearwater	–	Scar tissue formation, fibrosis	Charlton-Howard et al. 2023
Carassius auratus	Goldfish	PS (500 nm and 30 µm)	Olfactory impairment	Shi et al. 2021
Carassius auratus (Juveniles)	Goldfish (juvenile)	PVC microbeads (0.100–1000 µm)	Brain/liver damage, hormone disruption	Romano et al. 2020
Danio rerio	Zebrafish	PA, PE, PP, and PVC (~70 µm)	Intestinal lesions, villi cracking	Lei et al. 2018
Danio rerio	Zebrafish	PS (1 µm)	Minimal impact on early development	Qiang et al. 2020
Danio rerio & *Oryzias melastigma*	Zebrafish & Marine medaka	PE and PP (median: 33.7 mm)	Disrupted swimming; growth/reproductive issues	Cormier et al. 2022
Daphnia magna	Water flea	Red fluorescent polymer microspheres (1–5 µm)	Higher mortality, reduced growth/reproduction	Guilhermino et al. 2021
Lumbricus terrestris	Common earthworm	PS (100 nm, 1–100 µm)	Oxidative stress, DNA damage	Xu et al. 2021
Lumbricus terrestris	Common earthworm	PE (<150 µm)	Higher mortality, weight loss, growth reduction	Huerta Lwanga et al. 2016
Mytilus edulis	Blue mussel	HDPE (>0–80 µm)	Histological changes, immune	Moos et al. (2012)

			response, granulocytomas	
Nephrops norvegicus	Norway lobster	PP fibers (0.2 mm)	Reduced feeding/metabolism, weight loss	Welden and Cowie, 2016
Oreochromis urolepis	Wami tilapia larvae	PE (38–45 µm)	Villi degeneration	Mbugani et al. 2022
Pocillopora damicornis	Cauliflower coral	PS (1.0 µm)	Oxidative/immune stress via JNK/ERK pathways	Tang et al. 2018
Pomacea paludosa	Florida apple snail	PP (11.86–44.62 µm)	ROS increase, enzyme fluctuation, digestive damage	Jeyavani et al. 2022
Pomacentridae sp.	Damselfish	PS (200–300 µm)	Bold behaviour, increased mortality	McCormick et al. 2020
Rattus norvegicus (Female)	Female Wistar rat	PS (500 nm)	Ovarian fibrosis, apoptosis via oxidative stress	An et al. 2021
Rattus norvegicus (Male)	Male Wistar rat	PS (average 38.92 nm)	Testis damage, sperm abnormality, hormone disruption	Amereh et al. 2020
Sparus aurata	Gilthead seabream	LDPE pellets (100–500 µm)	Liver/brain enzyme activity, boldness, feeding increase	Rios-Fuster et al. 2021
Sparus aurata	Gilthead seabream	LDPE (200–1000 µm)	Intestinal damage, inflammation, necrosis	Varo et al. 2021

3. Impacts of Microplastics on Animal Health

3.1 Contaminated feed and forage

One of the pressing challenges in modern agricultural systems is the potential exposure of livestock to microplastics (MPs) through the ingestion of contaminated feed, forage, and drinking water. Chia et al. (2021) and Sarker et al. (2020) found that microplastics may reach terrestrial habitats by many means, such as the breakdown of plastic mulch, atmospheric deposition, and the use of sewage sludge or compost polluted with plastic as fertilizer. According to Martinez and Castelli (2023) and Zhang et al. (2023), forage crops that are cultivated in polluted soils have the potential to collect microplastics, and MPs may be directly deposited onto grazing fields and feed storage sites by air fallout. Soil and vegetation that cattle eat are contaminated when MP-laden water is used for irrigation (Jeong et al., 2023). Ruminants may consume these MPs by several means, such as ingesting them from pasture or contaminated field-sourced plant material in processed diets (Huerta Lwanga et al., 2016). Animals exposed to MPs may experience bioaccumulation of harmful chemicals, inflammatory reactions, and gastrointestinal problems, according to studies (Lee & Cha, 2023). Concerns about food safety, animal health, and possible human exposure via meat and dairy products are heightened by this kind of environmental pollution since animals are an essential part of the food chain (Senathirajah et al., 2021). The development of mitigation methods and regulatory regulations to guarantee the integrity of the food chain depends on our comprehension of the pathways and dangers of microplastic contamination in cattle diets.

3.2 Drinking water from polluted sources

Microplastics (MPs) in drinking water sources pose a substantial risk to cattle, especially in areas where water is derived from dirty rivers, lakes, or shallow groundwater aquifers. Livestock in agricultural settings often rely on surface water bodies or groundwater, which may be polluted by agricultural runoff, plastic litter, or the use of untreated wastewater for irrigation and livestock activities. Studies have found MPs in both surface and subsurface waterways, especially in rural and agricultural areas where animal rearing is common (Lee et al., 2022; Huerta Lwanga et al., 2016). Microplastics ingested via drinking water may accumulate in the gastrointestinal tract, possibly causing inflammation, gut microbiota alteration, oxidative stress, and the transfer of related harmful compounds or pathogens (Xiang et al., 2022; Lee & Cha, 2023). Because livestock represents a direct link in the food chain, contamination raises not only animal welfare concerns but also possible food safety implications for human consumers. As a result, monitoring and reducing microplastic pollution in livestock drinking water is critical for maintaining animal health and clean agricultural operations.

3.3 Ingestion of plastic waste on open grazing lands

The absorption of plastic garbage by cattle grazing in open fields is a growing problem, particularly in areas with inadequate waste management and extensive contamination. Grazing animals, such as cattle, sheep, and goats, are often exposed to plastic litter, which includes bags, wrappers, and packing materials that are collected in pastures and along roadsides. Because of their non-selective eating behaviour, ruminants may unintentionally absorb plastic objects when foraging, mistaking them for fodder or digesting them with polluted grass (Rochman et al., 2015). Plastics may build in the rumen or intestines after ingestion, causing health difficulties such as ruminal impaction, digestive blockage, internal injuries, poor food absorption, and, in extreme instances, death (Lee & Cha, 2023). The existence of persistent organic pollutants and additives in these polymers raises further toxicological concerns, possibly transmitting dangerous compounds into animal tissues and products such as milk and meat (Okoye et al., 2022). Furthermore, ingestion of plastics may reduce animal production and reproductive function, resulting in financial losses for producers. Preventive approaches, such as enhanced pasture fencing, ethical plastic disposal, and community awareness programs, are critical to reducing plastic exposure in grazing systems.

3.4 Sewage sludge application in pastures

The use of sewage sludge (biosolids) as fertilizer on pastures is prevalent owing to its nutrient-dense nature, yet it has also emerged as a significant pathway for microplastic (MP) pollution in terrestrial ecosystems. Sewage sludge has a significant concentration of microplastics derived from household wastewater, personal care items, synthetic fabrics, and industrial effluents (Chia et al., 2021; Okoye et al., 2022). When used in grazing fields, these microplastics may remain in the soil for prolonged durations, where they may be absorbed by plants or directly consumed by grazing animals via contaminated fodder and soil particles (Sarker et al., 2020). Livestock subjected to such conditions are susceptible to swallowing microplastics, which may result in gastrointestinal obstructions, inflammation, and the bioaccumulation of related poisons (Lee & Cha, 2023). Moreover, MPs in sludge may modify soil structure, microbial populations, and nutrient cycling, hence indirectly influencing pasture production and the long-term health of the soil (Xiang et al., 2022). Although regulatory criteria exist for biosolid utilization, the microplastic concentration is not consistently checked, which raises issues over the safety of sludge applications in pasture-based livestock systems. Consequently, reassessing sludge management strategies and using MP filtering technology in wastewater treatment facilities is crucial for alleviating this rising environmental threat.

4. Health Effects

Several critical questions remain unanswered regarding the health effects of microplastics (MPs) in cattle, particularly those exposed through contaminated feed, forage, water, or soil. Once ingested, MPs may trigger a range of physiological and pathological responses. MPs can remain in the gastrointestinal tract, causing mechanical injuries such as ruminal impaction, intestinal blockage, and mucosal abrasions (Lee and Cha, 2023). Additionally, MPs have been connected with oxidative stress, gut microbiota disruption, and inflammation of the intestinal lining, all of which can impair nutrient absorption and weaken immune function (Xiang et al., 2022). MPs also serve as carriers for hazardous environmental contaminants, including heavy metals, phthalates, and persistent organic pollutants (POPs). Once released into the body, these chemicals may exert cytotoxic effects, disrupt endocrine signalling, and bioaccumulate in edible tissues (Okoye et al., 2022). Such metabolic disruptions can adversely impact livestock productivity, reducing growth performance, reproductive efficiency, and milk produce.

Although most toxicological data stems from laboratory animal studies, limited but concerning evidence in cattle suggests that chronic MP exposure may alter the hormonal balance, elevate stress biomarkers, and affect liver enzyme activity (Lee & Cha, 2023). These health risks not only compromise animal welfare but also raise significant food safety concerns, particularly about the potential transmission of MPs and associated toxins through meat, milk, and other animal-derived products (Senathirajah et al., 2021). Given these findings, there is a pressing need for comprehensive risk assessments, targeted research in cattle, and regulatory frameworks to monitor and mitigate MP contamination in livestock production systems. Exposure pathways include ingestion through contaminated feed, water, and soil. Once internalized, MPs may cause gastrointestinal blockages, oxidative stress, inflammation, immune dysregulation, reproductive impairments and hepatic or renal dysfunction. Chronic exposure is linked to reduced productivity, altered gut microbiota, and possible bioaccumulation of co-contaminants (Figure 1).

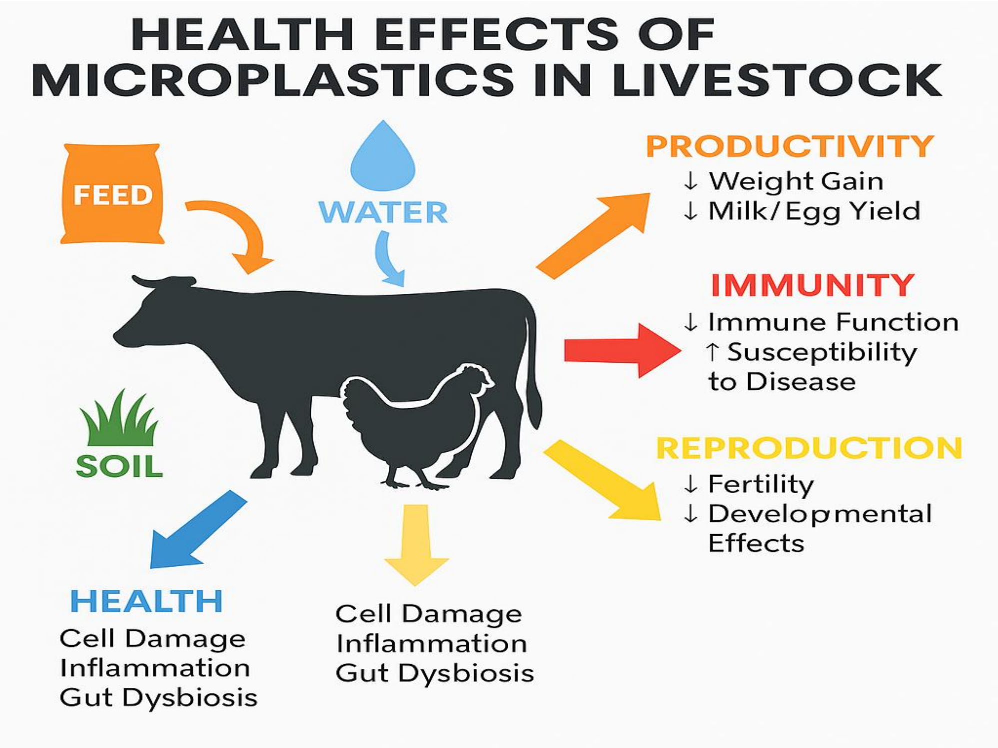

Figure 1. Health Effects of Microplastic Exposure in Livestock Animals.

4.1 Gastrointestinal blockage and inflammation

One of the most obvious and immediate health effects of cattle eating microplastics (MP) is that their gastrointestinal (GI) tract is blocked and inflamed. Animals that graze, including cows, sheep, and goats, are at risk of eating plastic trash and microplastics from pastures, feed, and water that are not clean. When eaten, non-biodegradable plastic particles might build up in the rumen or intestines, causing mechanical blockage, less movement, and ruminal impaction (Huerta Lwanga et al., 2016). In horrible situations, this obstruction may induce anorexia, bloating, less eating, weight loss, and even death since the digestive system does not work correctly for a long time (Lee & Cha, 2023). Microplastics may also damage the mucosal lining of the digestive system, which can cause inflammation, immune cells to move in, and changes in the shape of the gut. This inflammatory reaction might damage the gut barrier, make it more permeable, and make it harder for animals to absorb nutrients, which would harm their health and production (Xiang et al., 2022). Also, certain microplastics may leak harmful chemicals like bisphenol A (BPA) or phthalates, which makes oxidative stress and damage to the mucous membranes of the gut even worse (Okoye et al., 2022). Even though there has not been much research on cattle specifically, these results are similar to what has been shown in laboratory animals and raise severe concerns regarding the long-term and subclinical consequences of farm animals eating MP.

4.2 Disruption of liver function and enzyme profiles

Microplastics (MPs) in cattle have been associated with liver problems and changes in liver enzyme levels, which are early signs of systemic toxicity. Once swallowed, MPs may pass the intestinal barrier and go to the liver via the portal circulation. This can cause plastic particles or leached additives to build up in liver tissues (Lee & Cha, 2023). Studies on model animals have shown that microplastics cause oxidative stress, lipid peroxidation, and inflammatory reactions in liver cells. These are signs that the liver's detoxification processes are not working correctly (Xiang et al., 2022). There have not been many direct investigations on cattle, but comparable processes are thought to be at work. Exposure to MPs may cause elevated levels of liver enzymes such as alkaline phosphatase (ALP), alanine aminotransferase (ALT), and aspartate aminotransferase (AST). This might indicate that the liver cells are damaged or under metabolic stress (Okoye et al., 2022). All of these things are important for keeping animals healthy and productive. Long-term liver problems in farm animals may slow their development, weaken their immune systems, and lower the quality of their meat and milk, which can affect food safety. More study is needed to find safe levels of MP exposure for farm animals and to find out how much of it they can handle.

4.3 Oxidative stress and immune modulation

Animals, particularly cattle that are exposed to microplastics (MP), have been demonstrated to have a lot of oxidative stress and changes in their immunological responses. When animals eat MPs and their chemical additions, they may create reactive oxygen species (ROS) in their tissues, which can harm cells, cause lipid peroxidation, and break DNA (Xiang et al., 2022). This imbalance in oxidation may mess with how mitochondria work and start programmed cell death in the liver, intestine, and immune cells. This can affect the health and productivity of animals (Lee & Cha, 2023). Stress caused by MP is awful for the immune system. Furthermore, MPs may change the way cytokines are expressed, change the activity of T-cells and macrophages, and weaken mucosal immunity. This can cause either chronic inflammation or immunosuppression, depending on the kind of plastic and the degree of exposure (Okoye et al., 2022). These changes make the animal more likely to become sick, make vaccines less effective, and make it harder for the animal to deal with stress from the environment and its own body. In cattle, this kind of immune modulation may have an effect on animal welfare as well as disease resistance and product safety. This is because subclinical immunological dysfunctions might go unnoticed yet still harm the health of the whole herd. We need to undertake more research on farm animals in real life to figure out the dose-response relationships and the immunotoxic thresholds for MPs.

4.4 Bioaccumulation in edible tissues (raising food safety concerns)

Microplastic (MP) exposure in animals is a significant food safety problem since it may build up in edible tissues such as muscle, liver, kidney, and milk. After being eaten, MPs may move via the intestinal epithelium into the bloodstream, where they can reach other organs and get embedded in tissue matrices (Lee & Cha, 2023). Research involving fish, poultry, and laboratory mammals has confirmed the accumulation of microplastics (MPs) and associated toxicants in muscle tissues, indicating potential comparable risks in livestock species (Rochman et al., 2015; Senathirajah et al., 2021). Bioaccumulated MPs typically include harmful chemical additions, including bisphenol A (BPA), phthalates, and persistent organic pollutants (POPs) that may leak into animal tissues and then get into the human food chain (Okoye et al., 2022). These chemicals are known to mess with hormones, cause cancer, and damage nerves. Eating contaminated animal products may expose people to these chemicals over time, which is bad for their health (Xiang et al., 2022). In addition, MPs may carry harmful microorganisms and genes that make antibiotics less effective, which makes the health risks even worse (Senathirajah et al., 2021).

From a public health point of view, the buildup of MPs in the edible parts of cattle means that standardized monitoring techniques, risk assessment frameworks, and food safety rules need to be made to protect consumers. It is important to know how MPs stay in specific tissues and how quickly they go into meat and dairy products in order to make decisions on how to care for animals and safeguard consumers.

5. Knowledge Gaps and Research Priorities on Microplastic Exposure in Livestock and Food Safety

There is much evidence that microplastic (MP) contamination is harmful to aquatic habitats, but we still do not know much about how it affects land-based livestock animals. Most of the present information on how hazardous MP is comes from research on fish, rodents, and invertebrates. There is not much direct evidence on ruminants or poultry, which are very important to global food chains (Lee & Cha, 2023). There are not many experimental studies that look at how animals eat, absorb, distribute, and excrete MP. This makes it hard to figure out how much of it they really come into contact with and what health effects it has on them. Also, not much research has been done on the long-term consequences of chronic low-dose MP exposure on things like reproduction, immunity, and productivity.

Additionally, MPs have been found in feed, water, and soil, but there is no standard way to check for or measure microplastics in cattle tissues or agricultural matrices (Chia et al., 2021). There is not enough information on how MPs and other pollutants, such as heavy metals, pesticides, or antibiotics, work together. These pollutants may make animals that are exposed to them more harmful (Xiang et al., 2022). Another important gap is in food safety risk assessments: it is still not apparent whether and how much MPs or the chemicals that come with them get into food, milk, or eggs, which might be dangerous for people who eat them (Senathirajah et al., 2021). To fill up these gaps, further research has to be done on controlled exposure studies in cattle, the creation of biomarkers for MP exposure, and risk assessments that take into account One

Health's views. To build effective mitigation and policy frameworks, we need to use interdisciplinary methods that include veterinary science, toxicology, food safety, and environmental monitoring.

5.1 Long-term toxicokinetics in ruminants and monogastric

It is essential to know the long-term toxicokinetics of microplastics (MPs) in livestock in order to figure out the hazards of chronic exposure. However, this is still a significant area of animal and food safety research that has not been thoroughly studied. Toxicokinetics is the study of how a drug is taken in, spread about, broken down, and removed from an organism over time. There is growing evidence that cattle eat MPs, but there is not enough comprehensive research on how MPs act in the digestive tracts of ruminants and monogastric. Ruminants, including cows, sheep, and goats, have a stomach with many chambers. Microbial fermentation in the rumen may change the destiny of MPs, but we do not know how much they are broken up, kept, or moved into systemic circulation (Lee & Cha, 2023). Ruminants' prolonged gastrointestinal retention time may make it easier for MPs to build up and interact with gut microorganisms, which might affect how well they absorb hazardous substances like phthalates and heavy metals (Xiang et al., 2022). Monogastric, like pigs and poultry, have a more straightforward and quicker digestive tract, which may change how quickly they absorb tiny MPs (<1 μm) into the blood and tissues. There are not many studies that measure the size limits, absorption rates, and tissue-specific deposition of MP particles in these animals, however. Additionally, the clearance rates, possible hepato-renal loads, and biological half-lives of MPs or their chemical additions have not been determined for cattle species (Senathirajah et al., 2021). It is hard to guess what amounts of exposure are safe, what chronic toxicity means, or what carry-over dangers to humans are via meat, milk, or eggs without strong kinetic evidence. This gap makes it harder to create science-based rules and risk models for MP contamination in farming.

5.2 Transgenerational or reproductive effects

Microplastics (MPs) are becoming more and more known as possible reproductive toxicants. Experiments on model animals have shown that they may mess with gametogenesis, hormone control, and the growth of offspring. However, when it comes to livestock, particularly ruminants and monogastric, there is not much information on the impacts on reproduction and transgenerational effects. This is a significant gap in our understanding of agricultural toxicology and food safety. Microplastics, along with associated additives such as phthalates, bisphenol A (BPA), and polycyclic aromatic hydrocarbons (PAHs), are recognized as endocrine-disrupting chemicals (EDCs). These chemicals may act like or inhibit natural hormones, which can change oestrous cycles, sperm production, fertilization rates, and embryonic development (Xiang et al., 2022; Okoye et al., 2022). When rodents are exposed to MP, it lowers the quality of their sperm, changes the shape of their testicles, and makes their ovaries work less well. This suggests that cattle might be in danger if they are exposed to MP during their reproductive windows (Lee & Cha, 2023). Also, MPs may be able to get through the placenta, which would expose the foetus to both physical particles and chemicals that have been leached out. This has many worried about the repercussions that might happen throughout generations, such as epigenetic changes, developmental delays, low birth weight, and immune system problems in newborns. Such impacts, if validated in animals, might impair herd fertility, animal production, and long-term genetic health. However, there has not been any long-term or multi-generational research on livestock animals to look at in real life or a lab. We need reproductive toxicology studies that use livestock-relevant MP exposure models (dose, duration, particle size) right away because of the effects on the economy and food safety. These should look at levels of reproductive hormones, the health of gametes, the transport of nutrients via the placenta, the health of newborns, and any patterns of epigenetic inheritance.

5.3 Threshold levels of microplastic toxicity in livestock species

Determining the threshold levels of microplastic (MP) toxicity in livestock is essential for establishing safe exposure limits, informing risk assessments, and guiding regulatory policy. However, such thresholds remain undefined due to the deficiency of species-specific toxicological data, standardized methodologies, and long-term exposure studies in agricultural animals. To date, most microplastic toxicity thresholds are based on studies in aquatic species (e.g., fish, crustaceans) or laboratory rodents, which cannot be directly extrapolated to ruminants or monogastric livestock due to differences in digestive physiology, metabolic rates, and exposure routes (Lee & Cha, 2023). For example, ruminants possess a complex foregut fermentation system that may degrade or retain microplastics differently compared to monogastric like pigs and poultry, influencing both absorption and systemic distribution.

Critical factors influencing microplastic (MP) toxicity include particle size (with particles <1 μm capable of translocating across the gut barrier), polymer type (e.g., polystyrene vs. polyethylene), concentration and exposure duration, the presence of co-contaminants such as heavy metals and endocrine disruptors, and the developmental stage of the organism (e.g., juveniles are often more susceptible than adults).At present, no Lowest Observed Adverse Effect Level (LOAEL) or Observed Adverse Effect Level (NOAEL) values have been determined for microplastic (MP) exposure in cattle species. Initial results from in vitro studies and animal models suggest that prolonged exposure to MP concentrations ranging from 1 to 100 µg/kg body weight/day, or their chemical leachates, may elicit sub-lethal effects (Xiang et al., 2022; Okoye et al., 2022). Nevertheless, confirmed toxicological data relevant to cattle species is still deficient. These investigations must be meticulously coordinated with residue monitoring in animal-derived products to associate internal microplastic loads with possible concerns to food safety and human health.

Future research directions

To assess the environmental and health impacts of microplastics (MPs) and to inform effective mitigation and management strategies, future research must address several critical knowledge gaps. Most research has concentrated on aquatic creatures, so we do not have a complete picture of how terrestrial and aquatic animals react to MP exposure. Particularly in terrestrial animals, there is a lack of understanding of MP absorption, accumulation processes, and interspecific variability. While soil fauna may play a role in mitigating microplastic (MP) contamination, the pathways and fate of MPs, as they move from soil to plants and subsequently to animals, remain poorly understood—the role of microfauna in facilitating the entry of MPs into the soil food web warrants further investigation. Instead of focusing on individual species, future research should examine the impacts of MP on ecosystems and communities as a whole and evaluate how they affect ecological dynamics such as predator-prey interactions. The toxicological processes resulting from chemical interactions between microplastics (MPs) and living organisms—such as the leaching of antibiotics, heavy metals, flame retardants, and pharmaceuticals—require further in-depth investigation. Animals' long-term impacts and adaptive responses have received little attention in the present literature, in contrast to studies examining acute or short-term exposures. There has to be more research on the wider ecological effects of MP pollution on ecosystem processes and animal populations. The incorporation of automated detection, submicron-scale studies, and image-based structural and chemical characterization of MPs is crucial for enhancing data accuracy as analytical technologies develop. Although it is essential, interdisciplinary teams that bring together experts in fields like risk assessment, ecology, veterinary medicine, environmental chemistry, and toxicology are still in the minority. Developing thorough, multi-scale risk assessment frameworks that take into consideration the varied and complicated effects on ecosystems and animal health is necessary for efficient risk management related to MP pollution.

Conclusion:

The complicated link between exposure to microplastics (MPs) and health consequences in cattle has been summarised in this review, along with important conclusions and implications. It is becoming more and more clear that animals may be exposed to MP ingestion and accumulation via contaminated feed, forage, drinking water, and pasture conditions. Differences in digestive architecture, eating habits, and farming techniques all have an impact on physiological responses, but interspecies differences, such as those between ruminants and monogastric, also have a big effect. Mechanical gastrointestinal injury, oxidative stress, immunological modulation, hepatic dysfunction, and even reproductive impairment are all possible outcomes of MP exposure in cattle. It is dangerously possible for MPs to carry toxic substances, including heavy metals and endocrine-disrupting compounds that may build up in edible tissues. This is a big reason to be worried about food safety and human health. Animal welfare, agricultural output, and consumer safety all depend on our ability to comprehend this new danger. Pollutants provide a greater ecological threat when they enter livestock systems, which might have an impact on herd health, economic sustainability, and the stability of the food web. Toxicology, environmental chemistry, public health, and veterinary science must all work together in order to address these dangers. Policy frameworks need to account for the multifaceted nature of MP contamination by providing funding for research on long-term exposure, controlling the sources of contaminants in agricultural inputs, and mandating monitoring systems for goods obtained from animals. Given the significance of livestock to rural economies and human nutrition, it is crucial to do focused studies on exposure thresholds and chronic health consequences as soon as possible to prevent the potential transfer of MPs from animals to people. For this reason, it is imperative that scientific, regulatory, and agricultural stakeholders work together to address the critical problem of microplastic pollution as it pertains to cattle health. A dedication to sustainable, plastic-conscious agricultural practices and strong evidence-based policies are necessary to protect livestock welfare and food security from increasing environmental pollution.

Preserving animal well-being, guaranteeing food safety, and reducing environmental impacts in the long run all need this holistic strategy.

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