Review Article

Health Risks and Ecosystem-Level Implications of Veterinary Antiparasitic Drugs in Scarabaeid Dung Beetles

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Abstract | Dung beetles are crucial contributors to ecosystem health, supporting nutrient cycling, soil aeration, parasite suppression, and seed dispersal. Widespread use of veterinary antiparasitic drugs, particularly ivermectin and albendazole, poses a significant threat to their survival. Gut microbiota represents an essential component of dung beetle digestion, immunity, and reproduction. Drug residues excreted in livestock dung disrupt development, behavior, and microbial community composition, leading to impaired physiological performance. Microbial dysbiosis weakens individual fitness and triggers cascading ecological effects that compromise ecosystem functioning. Persistence of these residues in agricultural landscapes may undermine long-term ecosystem resilience and the sustainability of biodiversity. A comprehensive review of peer-reviewed studies published between 2000 and 2025 was conducted using major databases, including Google Scholar, PubMed, Scopus, Wiley Online Library, and Web of Science. Targeted keywords related to dung beetles, veterinary antiparasitic drugs, and gut microbiota were applied to ensure balanced coverage of toxicological, microbiome-mediated, and ecological evidence. The review synthesizes behavioral, physiological, microbiological, and transgenerational evidence, positioning gut microbiota alteration as a mechanistic bridge linking individual fitness loss to ecosystem dysfunction.

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Introduction

Dung beetles belong to the family Scarabaeidae, the largest group of insects found in all zoogeographic regions. They are keystone decomposers in terrestrial ecosystems, contributing to nutrient cycling, parasite suppression, and soil aeration (Byk *et al*., 2022; Daniel and Davis, 2023; Tovar *et al*., 2023). Dung beetles feed on dung, and they may feed on easily digestible fine particles, as well as high-quality food such as epithelial cells and bacteria from the gut of herbivores (Holter and Scholtz, 2007). Dung beetles offer key ecosystem services, including dung decomposition, seed dispersal, soil aeration, nutrient

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recycling, and parasite suppression in pastures (Ishikawa and Iwasa, 2020; Torabian *et al*., 2024). Among the key hazards to the health of dung beetles are excessive utilization of veterinary medications called antiparasitic drugs, which are discharged in cattle dung (Beynon *et al*., 2012; Sánchez-Bayo and Wyckhuys, 2019). Antiparasitic drugs like macrocyclic lactones and benzimidazole are commonly used endectocides to control livestock affected by parasites. Short-term behavioral and physiological effects of veterinary drugs have long-term consequences for ecosystem functioning and beetle populations (Verdú *et al*., 2018). Primarily, Ivermectin and albendazole are veterinary anthelmintic drugs that are excreted in the unmetabolized form in treated livestock. They have major negative impacts on the life stages of dung beetles. The egg-laying capacity, larval development, and survival rates are significantly slowed by ivermectin (O'HEA *et al*., 2010). The residuals of ivermectin impact adult emergence rate, survival, and fecundity. The lower doses of ivermectin can stop vitellogenesis by altering the morphology of the ovaries, causing oocyte resorption (González-Tokman *et al*., 2017; Martínez *et al*., 2017). While albendazole alters feeding behavior, fertility, oviposition, locomotory, and olfactory capacity in dung beetles (Biggs *et al*., 2025). This review synthesizes current evidence on the lethal, sublethal, microbiome-mediated, and transgenerational effects of veterinary antiparasitic drugs on dung beetles, and evaluates their broader implications for ecosystem functioning and sustainable livestock management.

Gut microbiota: A cornerstone of dung beetle health

Gut microbiota form a mutualistic association with dung beetles and play a central role in host physiology (Yasika and Shivakumar, 2025). Because dung is nutritionally imbalanced and rich in plant fibers, dung beetles rely on symbiotic microorganisms to compensate for digestive limitations. The dominant bacterial phyla reported in scarabaeid beetles include Firmicutes, Proteobacteria, and Bacteroides. These bacteria assist in executing several processes such as fermentation, detoxification, and digestion (Suárez-Moo *et al*., 2020). This functional diversity suggests that gut microbiota is integral not only to nutrition but also to environmental adaptation. Energy acquisition and developmental efficiency is promoted by the bacterial communities (Suárez-Moo *et al*., 2020).

Beyond digestion, gut microbiota contributes to immune regulation and pathogen resistance. By modulating immune signaling pathways and competing with harmful microbes, they enhance host survival and longevity (Ebert *et al*., 2021). This immune-microbiota interaction also influences reproductive success and population stability. Importantly, microbial composition varies between larval and adult stages, reflecting dietary differences and developmental requirements.

However, exposure to veterinary antiparasitic drug residues can disrupt this symbiotic equilibrium. The alteration in the gut microbial communities affects the functionality of the related bacteria, which eventually influences the health of dung beetles (Sarrocco, 2016). The health consequences are characterized by retarded growth, decreased body weight, low immunity and impaired functioning of the immune system. Maternal transmission is a major means of transfer of microbiota in dung beetle larvae. If the microbial dysbiosis occurs in early-life it can have transgenerational fitness consequences (Jones *et al*., 2025).

Together, these findings indicate that gut microbiota function as a mechanistic bridge linking antiparasitic drug exposure to reduced dung beetle health and ecosystem performance. These outcomes indicate that the gut microbiota do not just act as passive symbionts, but may serve as an active mediator. They are mediators of host resilience and are therefore a potentially crucial.

Microbiome shifts across life stages and environmental contexts

The richness of the gut microbiota of scarab beetles differs among different developmental stages and geographical distributions. The inner wall of brood balls itself contains a rich microbial diversity. When larvae feed on these brood balls, there is a substantial increase in microbial diversity in the larval intestines (Chen *et al*., 2024). In *Catharsius molossus*, the bacterial composition in brood balls mostly resembles that of the male gut microbiota rather than that of females. This resemblance represents the species-specific reproductive behavior. The males play a role in building brood balls, whereas the females lay eggs. Division of labor among males and females enables the transmission of gut-associated bacterial communities to the developing offspring from both parents. The dual microbial inheritance, maternal through direct contact with eggs and paternal through brood balls, potentially enhances early colonization and microbial diversity in the larval gut. As larvae grow, significant variations occur in their gut microbiota. These changes are characterized by a rapid increase in *Enterococcus* and *Lactococcus* symbiotic bacteria in the gut microbial composition (Chen *et al*., 2024). The taxonomical composition of gut microbiota changes with each development stage due to feeding variations in Copris incertus. Whereas, in the Australian dung beetles, the composition of gut microbiota is influenced by multiple factors. Factors include: Diet type, hindgut morphology, host taxonomy, social interactions, and phylogenetic relationships (Jácome-Hernández *et al*., 2023). Transmission of bacteria from mother to offspring in dung beetles occurs through maternal excretions in the brood ball, called the maternal gift (Estes *et al*., 2013; Parker *et al*., 2020). The maternal gift influences the host development, with a tentative exchange of maternal gift between different species of scarabaeoid beetles. The interspecific exchange may have antagonistic effects on survival, growth, and development time (Parker *et al*., 2021). Across studies, early developmental stages appear more sensitive to microbiome disruption than adults. The sensitivity suggests that antiparasitic exposure during breeding periods may have disproportionate long-term effects on population stability (Manning *et al*., 2017).

Antiparasitic drugs: Lethal and sublethal impacts

Antiparasitic drugs exert significant detrimental effects on coprophagous insect populations (Tovar *et al*., 2023). Frequently administered antiparasitic drugs like ivermectin and albendazole on livestock generate residues in their feces that are harmful to dung beetles. This can alter their behavior, fertility, and reproduction, decreasing their locomotion and olfactory abilities, causing microbes to be replaced or die off (Ambrožová *et al*., 2021; Pawar *et al*., 2021). Ivermectin residues in bovine dung pose a substantial threat to the reproductive success and developmental processes in the dung beetles. These effects are observed through reduced adult emergence, suppressed brood ball formation, and elevated mortality rates among larvae and pupae. The extended developmental durations and disruptions to gut bacterial assemblages are essential for physiological functions (Cooke *et al*., 2017). Macrocyclic lactones influence the behavior, development, and physiology of dung beetles. This influence is marked by delayed development, decreased survival and fecundity, and altered sex ratios (Mondragón-Ancelmo *et al*., 2019). As discussed earlier, the effects of ivermectin are dose-dependent. Higher doses reduce the muscle mass of dung beetles and increase male horn size. Whereas the intermediate doses increase lipid mass and change the sex ratio of offspring (Biggs *et al*., 2025). The persistence of drug residues in dung can last for several days to weeks in their biologically active concentrations. Effectively, this can impair the functioning of mature beetles at or below the doses that are detected in the field. The biomagnification of drug residues is also possible in insect tissue, escalating the toxic effects over time (Verdú *et al*., 2015). Experimental proof of the negative impacts of ivermectin has been documented on *Onthophagus landolti*. Consumption of dung treated with ≥1mg IVM/kg (Fresh weight) resulted in adult survival dropping drastically from 30-70% mortality. Lower doses of ivermectin suppressed brood production and significantly delayed larval development (Pérez-Cogollo *et al*., 2015). Whereas in *Scarabaeus cicatricosus*, a comparative analysis assessed antennal inhibition and ataxia. These findings have revealed that ivermectin exhibits 6-fold greater toxicity than other veterinary drugs in dung beetles (Verdú *et al*., 2018). Even the non-lethal doses of ivermectin can negatively impact. This could be deduced from the experimental work performed on *Thorectes lusitanicus*. Non-lethal ivermectin concentrations led to biomagnification in the fat body and hemolymph, impairing sensory functions and locomotion (Verdú *et al*., 2020). The widespread applications of antiparasitic drugs in cattle communities consistently reduce the diversity of dung beetles, along with functional impairment. Indirect effects include poor soil mixing, delayed dung decomposition, and periodic surface accumulation of dung (Verdú *et al*., 2018).

Albendazole, a benzimidazole anthelmintic, is another significant drug that also has toxicity effects on dung beetles directly or indirectly. The toxic effects get amplified, especially during flooding, because of the distribution of contaminated dung (Cooke *et al*., 2017). Its mechanistic action underlies the disruption of microtubule formation, which hinders cell division and nutrient uptake in target parasites. Its residues in dung beetles have been linked to affect feeding behavior, reduced fertility, locomotion, and delayed development (Verdú *et al*., 2018). Albendazole exhibits lower environmental durability and toxicity as compared to other macrocyclic lactones such as ivermectin. Antiparasitic efficacy should not be the only concern, but ecosystem compatibility must also be considered while dealing with these antiparasitic drugs (Forbes, 2021; Zhang *et al.*, 2022).

In comparison, albendazole impairs the formation of microtubules by affecting nutrient uptake and the division of cells, unlike other macrocyclic lactones, i.e., ivermectin (Yilmaz, 2019). Although dung beetles are typically less persistent in confronting albendazole, exposure in this species has been associated with impaired locomotion and significantly decreased feeding efficiency and fecundity. These highlight the importance of performing drug-specific ecological risk assessments rather than ivermectin-centric assessments.

The laboratory studies consistently demonstrate strong toxic effects of ivermectin on dung beetles. On the other hand, field-based studies report variable responses depending on species sensitivity, environmental persistence, and exposure duration. The variability among lab and field studies suggests the importance of ecological context. However, direct experimental findings on gut microbiota disturbance leading to reproductive failure are still scarce, offering a new area of research.

Ecological disruption and soil functioning

During dung breakdown, dung beetles interact with microorganisms (bacteria and fungi). Meanwhile, any negative impact on the health of dung beetles by the use of antiparasitic drugs would indirectly disrupt these microbial communities during the digestion of dung beetles and nutrient recycling (Shukla *et al.*, 2016). The Scarab beetles rely on the various communities of gut microbes that assist them in dung decomposition and derive the necessary nutrients (González-Tokman *et al.*, 2017). Scarabaeid beetles are involved in the dung recycling, soil quality, and nutrient recycling in the terrestrial ecosystems. Their gut microbiota is also distorted due to their exposure to veterinary antiparasitic drugs, leading to low survival and digestive dysfunction. The gut's microbial disruption impacts the efficient feeding of the beetles. It becomes difficult to decompose the dung, which slows down the nutrient recycling. Eventually impacting the soil composition and fertility. Additionally, the gut microbes' disproportion influences their behavior as well. It can also cause them to have reduced burrowing activities, again impacting the soil. Impacts on soil can result in less aeration, which normally affects the soil functioning in an ecosystem. Field studies report reductions of up to 30-70% in dung burial rates following ivermectin treatment, leading to prolonged dung persistence and reduced soil nutrient incorporation (Belete *et al.*, 2025). Taken together, these ecosystem-level disruptions suggest that veterinary drug exposure may shift pasture systems from biologically regulated nutrient cycling toward chemically dependent management regimes. Figure 1 explicitly explains the impact of these drugs on gut microbiota and ultimately the health of dung beetles.

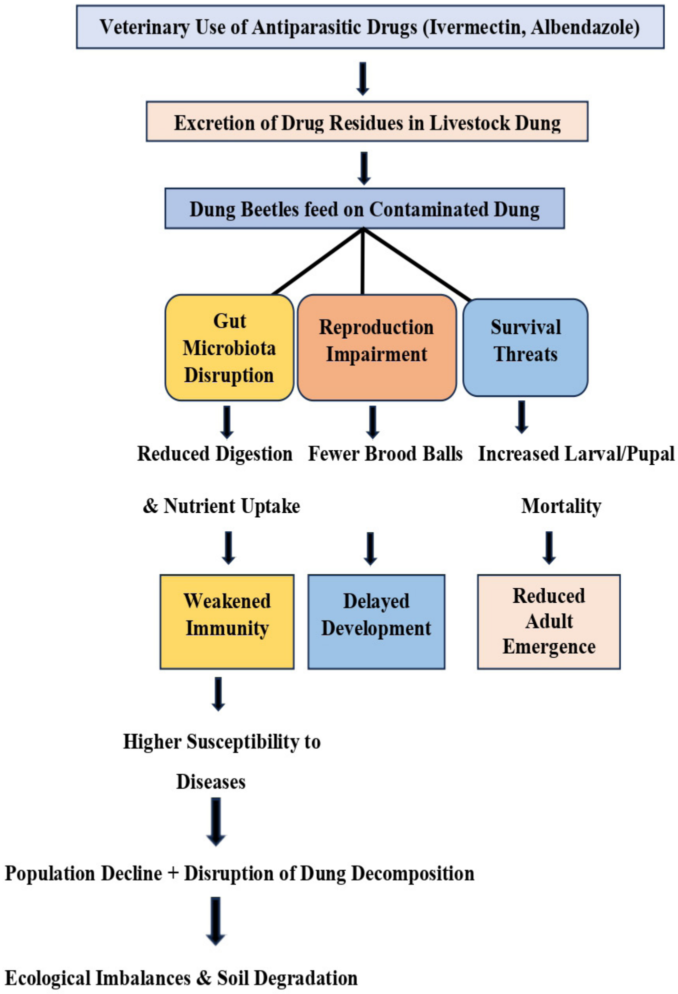

Figure 1: *Impact of veterinary antiparasitic drugs on gut microbiota and health of dung beetles.*

The "ecological trap" of drug-treated dung

The antiparasitic drug-treated cattle dung serves as a type of ecological trap, a non-optimal ecosystem that causes the dung beetles to form colonies, the results of which are critical (Beynon *et al.*, 2012). Dung beetles are primarily attracted to dung through olfactory cues derived from volatile organic compounds (VOCs). These compounds play a crucial role in regulating their resource selection (Frank *et al.*, 2018). The metabolites of antiparasitic drugs independently enhance dung attractiveness. The gut microbiota could modify the VOCs in the excrement (dung), thereby increasing its allure to dung beetles. The most abundant VOCs identified are ethyl butanoate, propyl butanoate (40-48% abundance in cattle-treated dung), 3-octanone, methyl anisole, and 3-octanole (Belo *et al.*, 2023; Urrutia *et al.*, 2024). The larvae of dung beetles are more sensitive to veterinary drugs than the mature dung beetles, and most of the adult beetles remain unaffected (Horvat *et al.*, 2012). As the dung will be used as a breeding site for dung beetles, upon hatching, the larval mortality will be observed. So, apparently, it even costs for beetles rather than benefits. However, empirical evidence for ecological traps in dung beetles remains limited, as few studies directly compare habitat preference with long-term fitness outcomes under field conditions (Robertson and Hutto, 2006). Without long-term fitness comparisons between treated and untreated habitats, the ecological trap hypothesis remains plausible but insufficiently validated.

Disease transmission and pest proliferation

Amongst the vast array of ecosystem functions, reductions in the richness of free-living stages of parasites and pests that grow in feces are regarded as most significant (Charlier *et al.*, 2020). As discussed earlier, the decline in dung beetle populations is observed due to antiparasitic drug residues has extensive ecological consequences. Their decline interferes with trophic relationships as beetles are involved in food chains. This can decrease biodiversity in the ecosystems since the beetles are prey to several predators like birds, reptiles, and small mammals (Wardhaugh *et al.*, 2001). The enhanced mortality of dung beetles can lead to inefficient decomposition of dung, thereby providing breeding sites for dung-breeding pests (flies, parasitic nematodes). This raises the possibility of disease transmission between wildlife and livestock (Jacobs and Scholtz, 2015). There are two primary mechanisms whereby beetles interfere with the life cycle of worms. The predatory species of dung beetles directly reduce pest populations by feeding on their larvae and eggs in the dung. While coprophagous species of dung beetles disrupt developing parasites, the infrastructure and microclimate of dung deposits, translocation, and survival are affected by changing the location of the dung pat (Dos Anjos *et al.*, 2024). Additionally, phoretic predatory mites (transported by dung beetles) suppress parasitic stages by feeding on the larvae present in the feces. These interactions make the scarab beetles vital contributors to naturally controlling parasitic infections in livestock ecosystems (Forbes and Scholtz, 2024). The principal competitors in oviposition sites to dung beetles are flies. Therefore, rollers relocate their food to minimize interspecific competition. Besides, dung beetles apply chemical substances on the food ball that can repel the predators and fly larvae (Ix-Balam *et al.*, 2018). As discussed earlier, delayed dung degradation increases pathogen persistence, which may indirectly elevate disease transmission risks in livestock systems (Bicudo and Goyal, 2003).

Selective species decline and loss of functional diversity

Veterinary anthelmintics based on ivermectin and albendazole are the main drugs used extensively in farmed animal production. The veterinary drugs have now acquired significance regarding their unintentional ecological consequences to the dung beetles (Verdú *et al.*, 2015). These non-target impacts of residual drugs in dung resulted in specific species decline in taxonomically vulnerable groups such as genus *Aphodius* and *Onthophagus* (Nichols *et al.*, 2008). Selective mortality occurs because species that handle fresh dung and develop slowly are more exposed to toxins, disrupting community structure. It causes a decline in functional diversity, whereby ecological roles are neglected (Holter and Scholtz, 2007). The ecosystem functions which may be affected include: soil aeration, dung degradation, and suppression of parasitic larvae. This malfunctioning of the ecosystem can lead to pasture fouling and increase pest proliferation (Mondragón-Ancelmo *et al.*, 2019). It can cause long-term effects on ecosystem stability, necessitating the need for chemical interventions. So, there is a cyclic association between drug consumption and biodiversity loss (Ambrožová *et al.*, 2021). As previously mentioned, the indirect effect of veterinary antiparasitic drugs includes the disturbance of gut microbiota. It results in severe ecological implications for seed dispersal, particularly in plants whose secondary seed burial depends on the dung beetles. Vegetation and regeneration dynamics, along with overall ecosystem stability, are ultimately affected.

Long-term and transgenerational effects

The negative effects of direct ivermectin exposure on dung-decomposing beetles are well documented, and its influence persists across successive generations

(Baena-Díaz *et al*., 2018; Crean and Bonduriansky, 2014). *Euonticellus intermedius* is quite sensitive to small doses of ivermectin. The body size, muscle mass, development, and fecundity are affected by smaller doses like 10-60μg/kg (Garric *et al*., 2007). The paternal exposure to ivermectin on dung beetles can reduce male horn size in the offspring, which is an important trait in sexual selection. While maternal and combined (male and female) exposure show such results. The effect of antiparasitic drugs persists across directly exposed species of dung beetles, affecting future generations (Baena-Díaz *et al*., 2018; Geary, 2005). In addition, the persistence of antiparasitic residues in the environment leads to enhanced chances of prolonged exposure. These effects can last and move to various generations (Ambrožová *et al*., 2021). Findings highlight the fact that exposure to these antiparasitic drugs is capable of altering population structure by sexual selection. It extends the long-term ecological consequences beyond the toxic effects.

Agricultural and conservation implications

The extensive use of veterinary antiparasitic drugs, particularly ivermectin and albendazole, exerts fundamental agricultural and ecological problems (González-Tokman *et al*., 2017). The residual traces of dung excreted in dung can persist in dung for a long time, often from several weeks to months. Such residues negatively impact the normal biological processes like larval development, adult locomotion, reproductive capacity, and sex ratio balance. Ultimately, this causes a severe reduction in species diversity and abundance of dung beetles in grazed ecosystems (Ambrožová *et al*., 2021; Ishikawa and Iwasa, 2020). Therefore, the disruption due to such drugs has vital implications on biodiversity conservation, ecosystem processes, and even the sustainability of agroecosystems (Martínez *et al*., 2017). Due to the treatment with antiparasitic drugs results in production losses in agricultural systems and reduced ecosystem functions (Pawar *et al*., 2021). Experimental studies have revealed that the diversity and species richness of several dung-dwelling taxa are reduced. Ivermectin has been reported to have specific species-level effects on dung beetles. Whereby the emergence of offspring and adult survival is reduced by higher doses of albendazole. Comparative study on diversity and abundance also reported a higher number of dung insects in organic farms (veterinary pesticide-free) than inorganic farms (veterinary pesticide used) (O'HEA *et al*., 2010; Sands and Wall, 2018). Paradoxically, excessive reliance on antiparasitic drugs may increase long-term parasite pressure by undermining natural biological control provided by dung beetles.

In Table 1, it is outlined that the ecological factors of dung beetles are quite significant in terms of diversity, ecosystem services, and the essentiality of gut microbiota. It further pinpoints the physiological and developmental effects of the veterinary drug residues, including delayed emergence, low fertility, and behavioral disorders. These impacts, together with species-specific sensitivities and the disparity between farming systems highlights the possible ecological impacts of extensive antiparasitic application.

Conclusion

Veterinary antiparasitic drugs, especially persistent compounds like ivermectin and albendazole, are of common use. This negatively impacts dung beetle populations by disrupting gut microbiota, reducing reproductive success, and impairing development. These alterations affect their ecological processes such as dung-decomposition, nutrient cycling, soil aeration, seed dispersal, and parasite control. There are also cascading environmental effects caused by drug exposure, which include reduced dung decay rate, reduced soil quality, and subsequent pest increase. These risks can be prevented by restricting the usage of drugs and scheduling the use to prevent the peak activity of beetles. The livestock management practices, like Integrated Pest Management (IPM) or specific selective solutions, have the potential of decreasing redundant applications. A preference should be placed on lower ecological persistence drugs and organic or sustainable farming methods that encourage the dung beetle diversity. Further studies on the long-term outcomes of antiparasitic medications on the microbiomes and the ecosystem services of the dung beetles would be of interest in the future. Studies are scarce on microbiome-mediated resilience, transgenerational bacterial transfer, and the development of dung beetle-friendly formulations. Ecological risk assessment and field-based validations will enable the optimization of the use of drugs and ensure the protection of biodiversity and ecosystem functioning.

Table 1: *Ecological and biological impacts of veterinary drugs on dung beetles.*

Aspect	Details	References
Diversity	35,000 species, found globally across all zoogeographic regions.	(Byk *et al.*, 2022; Daniel and Davis, 2023; Tovar *et al.*, 2023)
Ecosystem services	Dung decomposition, seed dispersal, soil aeration, nutrient recycling, parasite suppression.	(Ishikawa and Iwasa, 2020; Torabian *et al.*, 2024)
Role of gut microbiota	Aids in dung digestion (pectin, cellulose), immunity, nutrient absorption, and development. Varies between larval and adult stages.	(H. Y. Chen *et al.*, 2024; Suárez-Moo *et al.*, 2020)
Maternal microbial transmission	Bacteria are transferred via maternal excretions in the brood ball (maternal gift), critical for offspring survival and development.	(Estes *et al.*, 2013; Parker *et al.*, 2021; Parker *et al.*, 2020)
Drug Types	Ivermectin, albendazole, doramectin, and moxidectin are commonly used antiparasitic drugs in livestock.	(González-Tokman *et al.*, 2017; Jacobs and Scholtz, 2015)
Routes of exposure	Drug residues in cattle dung post-treatment serve as an exposure route for dung beetles.	(Beynon *et al.*, 2012; Sánchez-Bayo and Wyckhuys, 2019)
Physiological Impacts on Beetles	Altered behavior, reduced fertility and reproduction, impaired olfaction and locomotion, reduced body size, muscle mass, and increased mortality.	(Biggs *et al.*, 2025; Cooke *et al.*, 2017; Mondragón-Ancelmo *et al.*, 2019)
Developmental impacts	Delayed development, reduced adult emergence, suppressed brood ball formation, and extended larval and pupal stages.	(Cooke *et al.*, 2017; Tovar *et al.*, 2023)
Gut microbiota disruption	Loss or alteration of beneficial microbes affects digestion, immunity, behavior, and overall health.	(Ambrožová *et al.*, 2021; Shukla *et al.*, 2016)
Ecological consequences	Inefficient dung decomposition, soil compaction, reduced seed dispersal, lower biodiversity, disrupted food webs, and pathogen spread.	(González-Tokman *et al.*, 2017; Sands and Wall, 2018)
Species-specific sensitivity	Certain beetle species are more vulnerable to drug residues, leading to functional diversity loss and reduced ecosystem resilience.	(Biggs *et al.*, 2025; Sands and Wall, 2018)
Farming practices comparison	Higher dung beetle diversity in organic farms (no veterinary pesticides) vs. intensive/conventional farming systems.	(Sands and Wall, 2018)

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Novelty Statement

This review integrates gut microbiota disruption and transgenerational effects as central mechanisms linking antiparasitic drug exposure to long-term dung beetle population decline and ecosystem dysfunction.

Authors' Contribution

YC and MH conceived the idea and drafted the review article. IN draw diagram using MS Word software. SS made a table. KS, IA, and AN proofread and edited the final version of the article.

Generative AI and AI assisted technology statement
The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Statement of conflict of interest
The authors have declared no conflict of interest.

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