Review Article

Probiotics: Advantages and Disadvantages in Veterinary Medicine

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ABSTRACT

Probiotics primarily consist of beneficial bacteria, particularly from the genera *Lactobacillus* and *Bifidobacterium*, that when administered in adequate amounts, confer health benefits to the host. Probiotics have been shown to have various benefits in improving the health and productivity of livestock, including goats, camels, horses, dogs, and cats. The mechanisms through which probiotics exert their effects are complex and multifaceted. They can help maintain gut health by competing with pathogenic microorganisms for resources, thereby preventing infections. Additionally, probiotics can produce antimicrobial substances, such as bacteriocins, which inhibit the growth of harmful bacteria. They also play a role in enhancing the immune system by promoting the production of immunoglobulins and modulating inflammatory responses. Research has shown that specific probiotic strains can alleviate symptoms of gastrointestinal disorders, such as irritable bowel syndrome (IBS) and antibiotic-associated diarrhea. However, the use of probiotics also raises concerns about potential side effects and residues in animal products. Furthermore, the interaction of probiotic strains with other microorganisms during meat processing could result in the production of undesirable compounds, which may pose health risks to consumers. Another significant concern is the potential for probiotics to contribute to antibiotic resistance. Probiotic strains often harbor intrinsic and mobile genetic elements that confer resistance to various antibiotics. When consumed in high amounts, these probiotics can establish a reservoir of antibiotic-resistant genes, which may be transferred to pathogenic bacteria, leading to serious clinical ramifications. Further research is needed to fully understand the implications of probiotic use in animal production and human health. The conclusion of the text is that while probiotics offer numerous health benefits, their residues and metabolic byproducts can pose risks that warrant further investigation.

Keywords: Beneficial bacteria, Gastrointestinal disorders, Metabolic byproducts, Probiotics, Residues

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Introduction

Probiotics are characterized as viable microorganisms that, when delivered in sufficient quantities, provide health advantages to the host organism. This definition has been widely accepted and endorsed by authoritative bodies, such as the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) (Aladeboyeje & Şanlı, 2021; Markowiak & Śliżewska, 2017; Salminen & van Loveren, 2012). Probiotics are mostly made up of good bacteria, especially those belonging to the *Lactobacillus* and *Bifidobacterium* genera., which are commonly found in fermented foods, such as yogurt and kefir (Aladeboyeje & Şanlı, 2021; Parvez et al., 2006). Their health benefits are attributed to their ability to restore microbial balance in the gut, enhance the intestinal barrier function, and modulate immune responses (Leão et al., 2018; Suwal et al., 2018).

The health benefits of probiotics extend beyond the gastrointestinal tract. For instance, recent studies have indicated that probiotics can alleviate climacteric symptoms in menopausal women, suggesting their role in managing hormonal changes associated with menopause (Sivamaruthi et al., 2018). Additionally, probiotics have been linked to improvements in immune function, particularly in physically active individuals, where they may help mitigate the decline in immune response due to strenuous exercise (Khani et al., 2018; Norfuad et al., 2023). This immunomodulatory effect is crucial, as probiotics can enhance the secretion of immune modulators, thereby improving the host's resistance to infections (Adjei-Fremah et al., 2018). Moreover, the criteria for qualifying microorganisms as probiotics emphasize the necessity of maintaining sufficient levels of viable strains throughout the product's shelf life to ensure that the claimed health benefits are realized (Binda et al., 2020; Ouwehand, 2015). This includes adherence to good manufacturing practices to guarantee safety, purity, and stability of probiotic products (Binda et al., 2020). The diverse applications of probiotics in food products, particularly fermented foods, highlight their growing popularity and acceptance as functional ingredients in dietary supplements (Sarkar, 2020).

In addition to their direct health benefits, probiotics have also been studied for their potential in treating specific health conditions, such as antibiotic-associated diarrhea and mental health disorders, like postpartum depression and anxiety (Kołodziej & Szajewska, 2017; Slykerman et al., 2017). The ability of probiotics to modulate gut microbiota and enhance gut barrier function further supports their therapeutic potential (Aoki-Yoshida et al., 2016; Rahimi & Himmat, 2022).

Furthermore, the effectiveness of probiotics can be strain-specific, meaning that different strains may provide different health benefits (Miyazima et al., 2017). For instance, certain strains have been shown to reduce the levels of *Candida* species in oral environments, highlighting their potential in managing oral health (Li et al., 2014; Miyazima et al., 2017). In pediatric populations, probiotics have demonstrated benefits in preventing necrotizing enterocolitis in preterm infants, suggesting their importance in early life gut health (Westaway et al., 2022).

The mechanisms through which probiotics exert their effects are complex and multifaceted. They can help maintain gut health by competing with pathogenic microorganisms for resources, thereby preventing infections (Wong et al., 2015). Additionally, probiotics can produce antimicrobial substances, such as bacteriocins, which inhibit the growth of harmful bacteria (Wong et al., 2015). They also play a role in enhancing the immune system by promoting the production of immunoglobulins and modulating inflammatory responses (Balcázar et al., 2007; Suwal et al., 2018). Research has shown that specific probiotic strains can alleviate symptoms of gastrointestinal disorders, such as irritable bowel syndrome (IBS) and antibiotic-associated diarrhea (Guglielmetti et al., 2011).

Use of Probiotics in Veterinary Medicine

Probiotics also play a crucial role in veterinary medicine, particularly in enhancing animal health and productivity. Probiotics have been used successfully to control infection by *Salmonella* spp. in poultry and calves (Frizzo et al., 2012; Vandeplas et al., 2010).

These beneficial microorganisms, primarily lactic acid bacteria (LAB), are increasingly recognized for their ability to modulate the gut microbiota, improve immune function, and reduce the incidence of gastrointestinal diseases in various animal species. The use of probiotics is particularly significant in the context of rising antimicrobial resistance, as they offer a viable alternative to traditional antibiotics in livestock production (Arsène et al., 2021; Imperial & Ibana, 2016)

The administration of probiotics has been shown to positively influence the gut microbiota composition, promoting the growth of beneficial bacteria while inhibiting pathogenic strains. For instance, studies have demonstrated that probiotics can enhance nutrient digestibility and improve overall gut health, leading to better growth performance in livestock, such as swine and poultry (Park & Seo, 2023; Zammit & Park, 2023). This is particularly important in modern farming practices, where maintaining a balanced gut microbiota is essential for the health and productivity of animals (Arsène et al., 2021). Furthermore, the use of probiotics can reduce the need for antibiotics, thereby lowering the risk of antibiotic residues in food products and contributing to public health (Fijan, 2014).

In addition to their role in gut health, probiotics have been shown to exert immunomodulatory effects, enhancing the immune response in animals. This is particularly relevant in the context of infectious diseases, where probiotics can help mitigate the effects of pathogens, such as *Clostridium* spp. in horses and other livestock (Schoster, 2018; Schoster et al., 2015). The ability of probiotics to enhance immune function is linked to their capacity to produce short-chain fatty acids (SCFAs), which play a vital role in maintaining gut integrity and modulating inflammation (Park & Seo, 2023; Shehata et al., 2022). Moreover, the safety and efficacy of probiotics in veterinary applications are supported by ongoing research into their mechanisms of action and the specific strains that are most beneficial for different animal species. In the following, several studies on the use of probiotics in different animal species are discussed.

Use of probiotics in cattle and calves

The use of probiotics in cattle has gained significant attention due to their potential benefits in enhancing animal health and productivity. Probiotics have been shown to improve gut microbiota balance, enhance nutrient absorption, and reduce the incidence of diseases in cattle (Krishnan et al., 2020; Oyanguren et al., 2024). One of the primary benefits of probiotics in cattle is their ability to modulate the gastrointestinal microbiome. The administration of LAB as probiotics can lead to a significant reduction in pathogenic bacteria, such as *Escherichia coli*, in the feces of cattle (Mansilla et al., 2022). Furthermore, the modulation of the fecal microbiome through probiotics has been linked to enhanced feed efficiency and overall performance in feedlot cattle, particularly those on high-grain diets (Mansilla et al., 2021; Mansilla et al., 2022).

Probiotics also play a crucial role in the prevention of gastrointestinal diseases, which are common in cattle, especially in young calves. Research has shown that probiotics can reduce the severity and duration of diarrhea in calves, thereby improving their growth rates and overall health (Renaud et al., 2019). The use of specific probiotic strains has been associated with increased feed intake and improved weight gain, which are critical for the economic viability of cattle production (Gao et al., 2022). Additionally, probiotics have been explored as alternatives to antibiotics, addressing concerns regarding antimicrobial resistance in livestock (Aristimuño Ficoseco et al., 2018).

Moreover, probiotics have been found to enhance the immune response in cattle. For example, certain probiotic strains (LAB and *Dietzia* subsp.) can modulate immune responses, potentially leading to better resistance against infections and improved vaccination outcomes (Deng et al., 2015; Oyanguren et al., 2024). This immunomodulatory effect is particularly beneficial in managing diseases, such as paratuberculosis, where probiotics may assist in reducing the pathogen load (Karunasena et al., 2013).

The use of probiotics in calf rearing has also gained significant attention due to their potential benefits during the critical pre-weaning period. Research indicates that the administration of probiotics can enhance the growth performance of calves. For instance, Zabransky et al. (2014) demonstrated that probiotics support increased body weight in calves, particularly when combined with appropriate dietary supplements. Similarly, Ülger (2019) found that pre-weaning probiotic treatments significantly improved growth performance and biochemical blood parameters in Holstein calves, suggesting that probiotics can play a crucial role in enhancing weight gain during early life stages. Furthermore, a meta-analysis by Wang et al. (2023) corroborated these findings, indicating that probiotics can lead to improved average daily gain and feed efficiency in pre-weaning dairy calves.

In addition to promoting growth, probiotics have been shown to bolster the immune system of calves. Dar et al. reported that the use of probiotics and prebiotics in calves resulted in increased bactericidal and lysozyme activity in blood serum, which is indicative of enhanced immune function (Dar Hussain et al., 2018). Moreover, studies have highlighted that probiotics can reduce the incidence of diarrhea, a common issue in young calves that can severely impact their health and growth. For example, Cull et al. (2022) found that calves fed a milk replacer containing a multi-strain probiotic exhibited reduced diarrhea and lower mortality rates. This aligns with findings from Renaud et al. (2019) who noted that probiotics could effectively support the treatment of diarrhea in dairy calves. Moghadam et al. (2023) determined the beneficial effects of dietary supplementation of probiotic (Protexin) and chromium-methionine chelate (Cr-Met) on triiodothyronine (T3), thyroxine (T4), total protein, albumin, zinc, and growth body-weight gain in dairy calves after and before weaning. The study concluded that separate and mix feeding of dairy calves with chromium methionine and probiotic has no detectable effects on growth performance. Total protein and albumin were in the reference range, indicating that experimental animals did not have protein deficiency, and thyroid hormone and zinc were in normal range (Moghadam et al., 2023).

Razavi et al. (2019) investigated the effects of dietary supplementation of *Saccharomyces cerevisiae* cell wall (SCW) on acute-phase protein and liver function in high-producing dairy cows during the transition period. There was no evidence of a benefit in the SCW for adsorbing endotoxins in the diet in transition cows. Mirzaei et al. (2020) investigated the effect of dietary supplementation of bentonite and yeast cell wall on serum endotoxin, inflammatory parameters, and serum and milk aflatoxin in high-producing dairy cows during the transition period. The study suggests that SCW might be able to reduce the levels of aflatoxin in serum and milk, and the results may lead to a better understanding of using dietary supplements, such as bentonite and yeast cell wall, during the transitional period.

Use of probiotics in sheep and goats

Probiotics have emerged as a significant dietary supplement in sheep husbandry, offering various benefits that enhance growth performance, health, and overall productivity. The incorporation of probiotics into sheep diets has been shown to improve growth rates, enhance feed efficiency, and positively influence meat quality. For instance, Jiang et al., 2020, demonstrated that feeding lambs with probiotic-fermented feed resulted in a daily weight gain significantly higher than that of control groups, indicating the effectiveness of probiotics in enhancing growth performance in sheep. Similarly, Zhang et al. (2023). reported that probiotics can increase intramuscular fat and improve fatty acid composition in sheep, which is crucial for meat quality.

The health benefits of probiotics extend beyond growth performance. They play a vital role in maintaining gut health by balancing the intestinal microbiota, which can inhibit the growth of pathogenic bacteria. Rigobelo et al. (2013), highlighted that probiotics help establish a normal flora in sheep, particularly benefiting older animals that have a more developed microbiome compared to younger ones. This balancing act is crucial in preventing infections, such as those caused by *E. coli*, thereby improving the overall health and resilience of sheep against diseases (Rigobelo et al., 2013).

Moreover, probiotics have been shown to enhance the nutritional profile of sheep products. For example, the supplementation of probiotics has been associated with improved serum biochemical parameters, such as increased total serum protein and albumin levels, which are indicative of better health and nutrition in sheep (Sheikh et al., 2019). Additionally, probiotics can aid in the reduction of harmful metabolites (ammonia Nitrogen [NH_3-N]) in the rumen, thus improving the overall fermentation process and nutrient absorption (Jia et al., 2018). This is particularly important in the context of dietary interventions aimed at mitigating issues, like ruminal acidosis, where probiotics can help stabilize ruminal pH. Lactic acid–producing bacteria (*Lactobacilli* and *Enterococci*) provide a consistent supply of lactic acid in the rumen, stimulate lactate-utilizing bacteria, stabilize ruminal pH, and improve digestion (Dagnaw Fenta et al., 2023).

The application of probiotics in sheep farming also extends to reproductive performance. Research has indicated that the use of probiotic mixtures can enhance reproductive outcomes, which improve weaning weight and daily gain of lambs as much as live body weight and milk production of in ewes, demonstrating their potential as a biological feed additive (El-Hawy et al., 2019). This aspect is crucial for improving lamb production and ensuring the sustainability of sheep farming practices.

The use of probiotics in goats has garnered significant attention due to their potential benefits in enhancing health, improving growth performance, and optimizing milk production. One of the primary benefits of probiotics in goats is their ability to enhance nutrient digestibility and feed efficiency. Studies have shown that the inclusion of probiotics in the diet can lead to improved body weight gain and better feed conversion ratios (Ismail et al., 2018; Mirzaei et al., 2022). For instance Ismael et al. (2014), reported that bacterial probiotics significantly improved the body weight of goats compared to control groups, indicating enhanced food conversion and digestibility

Moreover, probiotics contribute to the modulation of the gut microbiota, which is essential for maintaining a balanced digestive system. The administration of specific probiotic strains has been shown to increase the diversity and abundance of beneficial bacteria while reducing the prevalence of pathogenic microorganisms (Mirzaei et al., 2022; Zhang et al., 2020). For example, Zhang et al. (2020) demonstrated that feeding weanling goats with *Bacillus amyloliquefaciens* resulted in a higher abundance of beneficial bacteria, such as Lactobacillus, while decreasing potentially harmful bacteria. This balance is crucial as it helps prevent digestive disorders and enhances the immune response of the animals (Du et al., 2018). In addition to improving gut health, probiotics have also been linked to enhanced milk production and quality in dairy goats. Probiotic supplementation has been shown to positively affect milk yield and composition, including increased concentrations of beneficial fatty acids (Apas et al., 2015; Ranadheera et al., 2019). For instance, the introduction of Lactobacillus and Bifidobacterium strains into the diets of lactating goats resulted in milk with improved fatty acid profiles, which are beneficial for both animal health and consumer nutrition (Apas et al., 2015). Furthermore, goat milk is recognized as an excellent carrier for probiotics, maintaining high viability during storage and processing, which is advantageous for the production of probiotic-rich dairy products (Ismail et al., 2018; Pradeep Prasanna & Charalampopoulos, 2019). The sensory attributes of goat milk products can also be enhanced through the use of probiotics. Although goat milk has a distinct flavor that may be less appealing to some consumers, the incorporation of probiotics can improve the sensory qualities of various dairy products, making them more palatable (Ranadheera et al., 2019). This is particularly important for the marketability of goat milk products, as consumer acceptance is a key factor in their success (Ranadheera et al., 2019). Kazemi et al. (2023) investigated the effects of dietary supplementation with probiotics and yeast cell walls on metabolic parameters and oxidative stress biomarkers in Saanen goat kids during the weaning challenge. The results showed that the administration of probiotics resulted in an improvement in the metabolic function of goat kids during weaning, but no significant effect of probiotics on the reduction of oxidative stress was observed. The study suggests that supplementation of diet with probiotics and yeast cell walls may improve lipid metabolism, but it did not result in a significant difference in weight gain at the weaning time in Saanen goat kids.

Use of probiotics in camels

The utilization of probiotics can play a significant role in camel husbandry, especially considering the unique digestive physiology of these animals. One of the primary benefits of probiotics in camels is their ability to improve gut health. Probiotics can help maintain a balanced intestinal microbiota, which is crucial for optimal digestion and nutrient absorption. Research by Davati et al. (2015) highlighted that LAB isolated from camel milk, such as *Lactobacillus casei* and *Enterococcus durans*, exhibit probiotic properties that can enhance gut health and potentially improve the overall health status of camels. These beneficial bacteria can inhibit the growth of pathogenic microorganisms, thereby reducing the risk of gastrointestinal diseases, which are common in camels due to their unique feeding habits and environments (Abdou et al., 2020).

Moreover, probiotics have been shown to enhance the immune response in camels. According to Fijan (2014), probiotics can stimulate various components of the immune system, leading to improved gut immune responses and intestinal homeostasis. This immunomodulatory effect is particularly important in camels, which often face stressors, such as extreme environmental conditions and dietary changes. By enhancing the immune system, probiotics can help camels better cope with these challenges, leading to improved health and productivity. The potential of probiotics as natural alternatives to antibiotics is another significant advantage. Abdou et al. (2020), noted that *Lactobacilli* isolated from camel milk demonstrated antagonistic activity against various pathogenic bacteria, suggesting that these probiotics could serve as effective substitutes for synthetic antibiotics in camel husbandry This is particularly relevant in the context of growing concerns about antibiotic resistance and the need for sustainable farming practices. The use of probiotics can help reduce the reliance on antibiotics while maintaining animal health and productivity. Furthermore, the incorporation of probiotics into camel diets may also contribute to improved metabolic health. Probiotics have been associated with various metabolic benefits, including enhanced nutrient utilization and reduced oxidative stress. Mishra et al. (2015) discussed the antioxidant potential of probiotics, indicating that their consumption can help reduce oxidative damage and improve overall health. This is particularly important for camels, which are often exposed to oxidative stress due to environmental factors.

Use of probiotics in horses

The use of probiotics in equine health has garnered attention due to their potential benefits in managing gastrointestinal health, treatment of acute enterocolitis, enhancing performance, and supporting recovery from injuries (Desrochers et al., 2005; Schoster et al., 2014). Probiotics, defined as live microorganisms that confer health benefits to the host, are particularly relevant in horses due to their unique digestive physiology and the prevalence of gastrointestinal disorders in this species.

One of the primary benefits of probiotics in horses is their role in improving gut health and microbiota balance. Probiotic supplementation has been shown to enhance the diversity of the gut microbiome, which is crucial for maintaining gastrointestinal health. For instance, Faubladier et al. (2013) reported that horses supplemented with *S. cerevisiae* exhibited greater bacterial diversity compared to control horses, suggesting a positive impact on gut health and fermentation activities. This is particularly important, as a diverse microbiome is associated with better digestion and nutrient absorption, which can enhance overall health and performance (Schoster et al., 2014).

Moreover, probiotics can influence metabolic parameters in horses. Laghi et al. (2018) demonstrated that *Lactobacilli* supplementation could modify hindgut pH and promote the proliferation of beneficial bacteria, thereby improving energy utilization during exercise. This aligns with findings from Garcia et al. (2015), who noted that supplementation with *S. cerevisiae* improved physical performance in trained horses. Such metabolic benefits are crucial for athletic horses, where optimal performance is often linked to efficient energy utilization. In addition to performance enhancement, probiotics have been investigated for their therapeutic potential in managing gastrointestinal diseases. Schoster et al. (2015) highlighted that probiotics could help prevent diarrhea and reduce the shedding of pathogens, such as *Clostridium difficile* in foals, indicating their role in disease prevention. Furthermore, probiotics have been shown to exert antimicrobial effects, which can be beneficial in controlling intestinal pathogens and maintaining gut integrity (Gotić et al., 2017). This is particularly relevant in the context of antibiotic use, where probiotics may mitigate the adverse effects on gut microbiota caused by antibiotic treatments (Zavistanaviciute et al., 2019).

However, the efficacy of probiotics in horses is not without controversy. Some studies have reported adverse effects, particularly in foals, where certain probiotic strains were associated with increased diarrhea (Ströbel et al., 2018). Additionally, the ideal dosages and specific strains of probiotics that confer the most benefit remain unclear. Schoster et al. (2016), noted variability in responses based on different probiotic formulations and dosages. This underscores the need for further research to establish standardized guidelines for probiotic use in equine medicine.

Use of probiotics in dogs and cats

Probiotics have garnered significant attention in veterinary medicine, particularly concerning their usage and benefits in dogs. The efficacy of probiotics in managing various gastrointestinal disorders in dogs has been supported by numerous studies. One of the primary benefits of probiotics in dogs is their role in alleviating gastrointestinal disturbances, such as diarrhea. A clinical trial demonstrated that an orally administered anti-diarrheal probiotic paste significantly improved outcomes in dogs with acute diarrhea, highlighting the potential of probiotics to accelerate the resolution of nonspecific diarrhea and enhance recovery from conditions, like parvoviral enteritis (Nixon et al., 2019). Additionally, probiotics have been shown to restore the normal microbiome in dogs suffering from acute hemorrhagic diarrhea syndrome, further emphasizing their therapeutic potential (Jugan et al., 2023; Nixon et al., 2019). Moreover, probiotics are believed to modulate the immune response in dogs. Research indicates that probiotic treatment can lead to increased serum IgG levels, which are crucial for immune function (You et al., 2022). This immune modulation is particularly relevant in the context of gastrointestinal diseases, where an enhanced immune response can help combat infections and maintain gut health (Jensen & Bjørnvad, 2019).

The specific strains of probiotics used can significantly influence their effectiveness. For instance, studies have isolated and characterized *Lactobacillus* strains from canine feces, demonstrating their potential as effective probiotics due to their origin from the canine gut (Coman et al., 2019; Grześkowiak et al., 2014). This strain specificity is crucial, as probiotics derived from non-canine sources may not exhibit the same beneficial properties in dogs (Coman et al., 2019). Furthermore, the administration of multi-strain probiotics has been associated with improved clinical outcomes in dogs with idiopathic inflammatory bowel disease (IBD), suggesting that a tailored approach to probiotic selection may yield better results (Rossi et al., 2014; White et al., 2017).

Despite the promising evidence supporting the use of probiotics in dogs, there are also challenges and limitations. Some studies have reported mixed results regarding the efficacy of probiotics in chronic conditions, such as chronic enteropathy, where the benefits may not be as pronounced (D'Angelo et al., 2018; Dandrieux et al., 2019). Additionally, the individual responses to probiotic supplementation can vary based on the dog's baseline microbiome composition, indicating that personalized approaches may be necessary for optimal outcomes (Tanprasertsuk et al., 2021).

The utilization of probiotics in feline health has also garnered increasing attention due to their potential benefits in enhancing gut health and overall well-being in cats. Probiotics have been shown to positively influence the gut microbiota composition, which is critical for maintaining gastrointestinal health and immune function in cats (Li et al., 2023; Yang & Wu, 2023). Recent studies have demonstrated that specific probiotic strains can significantly improve the gut microbiome of cats. For instance, the supplementation of *Lactobacillus acidophilus* in healthy adult cats resulted in an increased count of beneficial *Lactobacillus* species and a reduction in harmful *E. coli*, thereby enhancing fecal quality and intestinal health (Li et al., 2023). Furthermore, a study indicated that a multistrain probiotic could effectively alter the fecal microbiota and increase the production of SCFAs, which are vital for gut health and metabolic functions (Li et al., 2023; Yang & Wu, 2023). The production of SCFAs is particularly important as they serve as an energy source for colonocytes and play a role in regulating inflammation and immune responses (Nagpal et al., 2018). In addition to improving gut health, probiotics have been associated with specific health benefits in cats suffering from chronic conditions. For example, a study on cats with chronic kidney disease (CKD) revealed that a probiotic mixture led to a downregulation of harmful plasma indicators and improved quality of life parameters, such as appetite and activity levels (Tsai et al., 2024). This suggests that probiotics may not only support gut health but also have systemic effects that can enhance the quality of life in cats with chronic illnesses. Moreover, the host specificity of probiotics is crucial for their effectiveness. Research has shown that probiotics derived from feline sources tend to be more effective in managing gut health compared to those from other species (Jang et al., 2024; Kim et al., 2021). This specificity underscores the importance of selecting appropriate strains that are well-suited to the unique gastrointestinal environment of cats, which is characterized by a high-protein, low-carbohydrate diet (Jang et al., 2024).

The impact of probiotics on the gut microbiome is also influenced by the overall dietary composition and the presence of prebiotics. For instance, the combination of probiotics with prebiotics, such as galactooligosaccharides, has been shown to enhance the stability of the gut microbiome and promote the growth of beneficial bacteria while mitigating potential adverse effects from probiotic supplementation (Ma et al., 2020). This synergistic approach can lead to improved gut health outcomes and a more resilient microbiome.

Use of probiotics in poultry

The use of probiotics in poultry, particularly in chickens, has gained significant attention due to their potential benefits in enhancing growth performance, improving gut health, and serving as alternatives to antibiotics. In poultry production, probiotics are primarily utilized to promote gut health, improve feed efficiency, and enhance overall productivity. One of the primary benefits of probiotics in poultry is their ability to improve growth performance. Studies have shown that probiotic supplementation can lead to increased weight gain and better feed conversion ratios in broiler chickens. For instance, Khan et al. (2023) reported that probiotics significantly enhance weight gain and feed conversion efficiency in broilers, highlighting their role in optimizing growth performance. Similarly, Yu et al. (2022) demonstrated that specific probiotic strains, such as *Bacillus coagulans* and *Lactobacillus plantarum*, positively impacted the growth performance of broilers, indicating that the choice of probiotic strain can influence outcomes.

In addition to growth performance, probiotics play a crucial role in maintaining gut health by modulating the intestinal microbiota. This modulation helps inhibit the growth of pathogenic bacteria, thereby reducing the incidence of gastrointestinal diseases. Johnson et al. (2023) emphasized that probiotics, particularly *Lactobacillus* strains, are effective in inhibiting pathogens and improving gut health in poultry. Furthermore, Mañes-Lázaro et al. (2017) indicated that certain probiotic treatments could reduce colonization by harmful bacteria, such as *Campylobacter jejuni*, which is known to cause food-borne illnesses. This protective effect underscores the importance of probiotics in enhancing the safety of poultry products. Probiotics also contribute to the overall immune function of poultry. The addition of probiotics to chicken diets has been associated with enhanced immune responses, which can lead to improved resilience against diseases. For example, Payen et al. (2023) noted that probiotics could modulate the immune system, thereby promoting better health and productivity in poultry. Additionally, the combination of probiotics with digital livestock systems has been shown to further enhance immune functions and growth performance, suggesting that integrated approaches may yield even greater benefits (Zammit & Park, 2023).

Moreover, the use of probiotics can serve as a sustainable alternative to antibiotics in poultry production. Nunes et al. (2012). highlighted the potential of probiotics to replace antibiotics, thereby addressing concerns related to antibiotic resistance and promoting more sustainable farming practices This shift is particularly important, as the poultry industry seeks to reduce its reliance on antibiotics while maintaining high production standards.

Use of probiotics in fishes

Probiotics have emerged as a significant area of research in aquaculture, particularly concerning their role in enhancing fish health, growth performance, and immune responses. For instance, Wang et al. (2018). highlight the importance of understanding fish gastrointestinal microbiota to develop effective probiotics that can enhance fish health and growth through targeted interventions in the gut microbiome. This is supported by studies demonstrating that specific probiotic strains, such as *Lactobacillus paracasei*, can improve growth rates and intestinal microbiota balance in fish, leading to better overall health and resistance to infections (Sagymbek et al., 2022).

Moreover, the effects of probiotics on fish growth performance have been extensively documented. For example, research on the Beluga sturgeon indicated that diets supplemented with probiotics not only improved growth performance but also enhanced fatty acid profiles and digestibility (Montazeri Parchikolaei et al., 2021). Similarly, studies on cichlids and tilapia have shown that probiotic supplementation can significantly increase nutrient digestibility, thereby promoting better growth outcomes (Sankar et al., 2017). The economic efficiency of using probiotics in aquaculture is underscored by their ability to improve feed utilization and growth rates, which can lead to increased profitability for fish farmers (Sagymbek et al., 2022). The immunomodulatory effects of probiotics are another critical aspect of their application in aquaculture. Probiotics have been shown to enhance the innate immune responses of fish, making them more resilient to pathogenic challenges. For instance, Mohapatra et al. (2014) reported that probiotics could lower blood glucose levels and improve immune responses in *Labeo rohita*, particularly under stress conditions. This immunological benefit is further corroborated by studies indicating that probiotics can enhance the overall health of fish by modulating immune parameters and improving resistance to diseases caused by bacteria, such as *Aeromonas hydrophila* (Harikrishnan et al., 2010; Ramesh & Souissi, 2018).

However, it is essential to consider the dosage and specific strains of probiotics used, as excessive levels can disrupt the intestinal flora and negatively impact fish health. Research indicates that while low to moderate levels of probiotics can be beneficial, high concentrations may lead to adverse effects, including impaired growth and immune responses (Montazeri Parchikolaei et al., 2021; Sankar et al., 2017). Thus, determining the optimal probiotic dosage is crucial for maximizing the benefits while minimizing potential drawbacks.

Side Effects of Probiotics

Despite the numerous benefits associated with probiotic consumption, there are also potential side effects that warrant consideration. Some studies have reported gastrointestinal discomfort, such as bloating and gas, particularly when probiotics are first introduced into the diet (Grossenbacher et al., 2016; Lynch et al., 2021). Additionally, there is a risk of infections in immunocompromised individuals, as certain probiotic strains may translocate from the gut to the bloodstream, leading to bacteremia (Sanders et al., 2013; Siesto et al., 2022). Additionally, there are concerns regarding the safety of probiotics during sensitive periods, such as pregnancy and lactation. Some studies have reported adverse effects, including an increased risk of pre-eclampsia associated with probiotic administration (Deng et al., 2022). While systematic reviews suggest that the overall health risks of probiotics may not be significant for mothers or infants, the potential for adverse outcomes necessitates careful consideration and monitoring (Sheyholislami & Connor, 2021).

Furthermore, the efficacy of probiotics can be influenced by various factors, including the strain used, the individual's existing gut microbiota, and the method of delivery (Han et al., 2021; Talebian et al., 2022). For instance, the survival of probiotics during gastrointestinal transit is a significant challenge, as many strains do not withstand the harsh conditions of the stomach and intestines (Bhat et al., 2015; Lai et al., 2022). Recent research has also highlighted the importance of strain specificity in determining the health effects of probiotics. Different strains can have varying impacts on health, and not all probiotics confer the same benefits (Kobyliak et al., 2016; Talebian et al., 2022). This heterogeneity underscores the need for more targeted research to identify which strains are most effective for specific health outcomes (Kechagia et al., 2013; Talebian et al., 2022). Additionally, the source of probiotics, whether derived from dairy or other unconventional sources, can influence their functional characteristics and health benefits (Sionek et al., 2023; Sornplang & Piyadeatsoontorn, 2016).

Another significant concern is the adverse effects that may arise from the consumption of probiotic-enriched dairy products. For instance, the review by Elshaghabee, (2023) highlights that while probiotics can enhance gut health, they may also lead to adverse effects in some individuals, particularly those with compromised immune systems or severe lactose intolerance. Another critical aspect is the potential for allergic reactions or intolerance associated with dairy-based probiotics. Some individuals may experience allergic responses to milk proteins or lactose, which can be exacerbated by the presence of probiotics (Natt & Katyal, 2022). This highlights the need for careful consideration of the target population when developing probiotic dairy products, as not all consumers may benefit from or tolerate these products well.

As mentioned above, the use of probiotics in animal husbandry has gained attention as a potential alternative to antibiotics for enhancing production performance and improving animal health. While they are widely recognized for their positive effects on gut health, there is growing concern regarding the potential adverse effects associated with their use, particularly in the context of probiotic residues. These residues can arise from the metabolic byproducts of probiotics or from the probiotics themselves, which may lead to unintended consequences for human health. Therefore, the implications of probiotic residues in meat, milk, and eggs on human health warrant careful consideration. The metabolic byproducts of probiotics, such as SCFAs, while generally beneficial, can also have adverse effects if produced in excess or inappropriately. For instance, an overproduction of SCFAs may lead to gastrointestinal disturbances, including bloating and diarrhea (Duysburgh et al., 2023). The impact of these metabolites on gut health is complex and can vary significantly among individuals, depending on their unique gut microbiota composition and health status (Wieërs et al., 2020). While probiotics are generally recognized as safe and beneficial, the presence of certain strains in meat could lead to unintended consequences. For instance, the metabolic byproducts of probiotics, such as lactic acid and hydrogen peroxide, can alter the organoleptic properties of meat, potentially leading to rancidity and discoloration (Neffe-Skocińska et al., 2016; Wójciak et al., 2012). Furthermore, the interaction of probiotic strains with other microorganisms during meat processing could result in the production of undesirable compounds, which may pose health risks to consumers (Geiker et al., 2021). Additionally, the long-term effects of consuming meat with probiotic residues are not fully understood. Some studies suggest that probiotics may have beneficial effects on human health, such as enhancing gut microbiota balance and potentially reducing the risk of certain diseases (Malmir et al., 2021; Pogorzelska-Nowicka et al., 2018). However, the implications of consuming meat products containing live probiotics or their metabolites are still under investigation, and more research is needed to ascertain their safety and health effects on humans (Geiker et al., 2021).

Another significant concern is the potential for probiotics to contribute to antibiotic resistance. Probiotic strains often harbor intrinsic and mobile genetic elements that confer resistance to various antibiotics. When consumed in high amounts, these probiotics can establish a reservoir of antibiotic-resistant genes in the human gut, which may be transferred to pathogenic bacteria, leading to serious clinical ramifications (Zheng et al., 2017). This phenomenon is particularly alarming given the increasing prevalence of antibiotic-resistant infections globally. Moreover, the introduction of probiotics into the gut microbiome can disrupt the delicate balance of microbial communities. For instance, while probiotics are intended to restore gut health, their presence can sometimes lead to dysbiosis, characterized by an imbalance in microbial populations. This dysbiosis can result in increased intestinal permeability, often referred to as "leaky gut," which is associated with chronic inflammation and various health issues (Hiippala et al., 2018; White, 2016). The modulation of gut microbiota by probiotics can also inadvertently promote the growth of pathogenic bacteria, particularly if the probiotics are not well-matched to the individual's existing microbiome (Zhao et al., 2021).

Conclusion

In conclusion, while the use of probiotics in livestock production presents numerous benefits, including improved animal health and meat quality, the potential side effects of probiotic residues on human health require further exploration. While probiotics offer numerous health benefits, their residues and metabolic byproducts can pose risks that warrant further investigation. The potential for antibiotic resistance, dysbiosis, adverse effects during pregnancy, and gastrointestinal disturbances highlights the need for a nuanced understanding of probiotic use. Ongoing research is essential to fully understand the long-term implications of probiotic use in livestock and its effects on human health and future research should focus on establishing clearer guidelines for the safe use of probiotics, especially in vulnerable populations, to mitigate potential risks while harnessing their therapeutic potential.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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