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OVERVIEW OF *Bifidobacterium*, *Lactobacillus* AND *Enterococcus* CONTAINING SYNBIOTIC SUPPLEMENTATION IN POULTRY, SWINE AND RUMINANT NUTRITION

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Abstract: The continuous use of antibiotics as growth promoters in livestock production has raised significant global concerns due to its contribution to antimicrobial resistance (AMR) and the potential residue deposition in animal products, posing indirect risks to consumers. This critical issue necessitates the urgent development of effective natural alternatives capable of mitigating the negative impacts of antibiotic overuse without compromising overall animal health and productivity. Probiotic genera such as *Lactobacillus*, *Enterococcus*, and *Bifidobacterium* have been confirmed to have enormous benefits, being part of the microbial communities in the gut of livestock, therefore same is expected to be achieved when they are part of a synbiotic combination especıally when incorporated as feed additives in livestock nutrition. Consequently, this article gives an overview of the efficacy of synbiotic formulations—particularly those incorporating *Bifidobacterium*, Lactobacillus, and *Enterococcus* species —across ruminants, poultry, and swine. By synthesizing more recent researches, it aims to assess the impact of these synbiotics on livestock gut health, growth performance, and disease resistance and to establish their viability as sustainable replacements for antibiotic growth promoters.

Keywords: Antibiotics, Synbiotics, Gut health, Antimicrobial resistance, Probiotics

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1. Introduction

The gastrointestinal tract (GIT) contains a diverse group of microorganisms that influence farm animal health. At birth, the gut is free from any form of microorganisms; however, as the animal matures, microbial succession gradually establishes a stable microbial community, which directly influences host wellbeing. The composition of the gut microbiota is shaped by various factors, including age (Jiangrang et al., 2003), diet (Corrigan et al., 2015), rearing system (Chen et al., 2018), and the environment (Lundgren et al., 2018). These interacting factors lead to the development of a dynamic and complex microbial ecosystem, predominantly composed of bacteria, though archaea, fungi, and protozoa may also be present in smaller numbers. The relationship between gut microbiota and the host animal is synbiotic with both parties deriving benefits. The host provides a stable, nutrient-rich environment supporting microbial growth and activity. In return, the microbiota performs several critical functions that promote host health (Thursby and Juge, 2017). One of the most important roles of gut microbes is the production of short-chain fatty acids (SCFAs) through the fermentation of dietary fibers which serve as energy sources for intestinal cells and help regulate immune responses by reducing inflammation and promoting the development of protective immune cells (Malys et al., 2015). Beyond their role in maintaining gut integrity and modulating immunity, gut microorganisms are actively involved in nutrient metabolism and vitamin synthesis, which are crucial for various metabolic processes (Rowland et al., 2018). The importance of gut health as an indicator of overall animal health cannot be overstated. A well-balanced gut microbiota is associated with improved feed efficiency, better growth rates, and enhanced productivity in livestock (Kraimi et al., 2019).

Antibiotics have been used in livestock for many years to promote growth, improve feed use, and boost productivity. Using antibiotics as growth promoters has greatly boosted livestock production by improving animal health, growth, and feed efficiency. However, their overuse has led to major public health concerns, including antibiotic resistance and foodborne infections like *Salmonella* and *Escherichia coli*. Many countries, including the U.S, China, have effectively banned or restricted antibiotic use in animal feed to address these issues (Wallinga et al., 2022; Wen et al., 2022) whereas, in Nigeria, despite the imposition of an embargo on antibiotic usage, the policy has proven ineffective due to poor implementation and enforcement (Okonkwo and Ogbonna, 2018). To address these concerns, researchers are looking into natural alternatives like probiotics, prebiotics, synbiotics, postbiotics, enzymes, and plant extracts to reduce reliance on antibiotics and support sustainable animal farming.

Among these alternatives, synbiotics—a mix of probiotics (beneficial microbes) and prebiotics (food for those microbes)—have shown great promise. Synbiotics help balance gut bacteria, improve digestion, and strengthen the immune system (Gibson et al., 2017; Swanson et al., 2020). There are two types: complementary synbiotics, where both the different microbial strains enhances the functions of one another and invariably benefit the animal, and synergistic synbiotics, where the prebiotic boosts the specific probiotic's effect but neither is effective alone (Pandey et al., 2015). Synbiotics can increase the chances of probiotic survival in the harsh upper gut, helping them work better and longer. This makes them a useful tool in animal production to replace antibiotics while still supporting animal health and performance (Hamasalim, 2016).

Strains of *Lactobacillus* (e.g., *L. plantarum*), *Enterococcus*, and *Bifidobacterium* have demonstrated significant efficacy in promoting animal health, with their distinct functional properties making them ideal candidates for synbiotic formulations. Wang et al. (2018) documented that *L. plantarum ZLP001* strengthened intestinal barrier function by preserving tight junction protein expression during enterotoxigenic *Escherichia coli* (ETEC) challenge, while concurrently modulating gut microbial communities, specifically elevating butyrate-producing *Faecalibacterium* populations as well as suppressing pathogenic *Clostridium sensu stricto 1* (Wang et al., 2018). Cao et al. (2013) reported that dietary supplementation with *Enterococcus faecium* in broiler chickens improved growth indices such as body weight gain and feed conversion ratio, enhanced intestinal morphology, and stimulated immune responses, while concurrently decreasing colonization by pathogenic *E. coli K88*. In another investigation, Santini et al. (2010) demonstrated the anti-microbial capacity of select bifidobacterial strains against *Campylobacter jejuni*, potentially mediated through organic acid secretion—a mechanism corroborated by Chaveerach et al. (2004), who suggested that organic acids in drinking water can influence microbial composition, though without measurable impacts on growth parameters or clinical health status. Contrastingly, investigations employing multi-strain probiotic preparations (O'Dea et al., 2006; Mountzouris et al., 2007) reported marginal but statistically significant improvements in performance indices, underscoring the potential synergistic effects of microbial consortia in gastrointestinal modulation.

Environmental sustainability is a core focus of the Sustainable Development Goals (SDGs). One major challenge associated with intensive livestock production is ammonia emission, a significant environmental degradation factor that adversely affects both the environment and farm workers. This concern prompted the National Emission Ceiling Directive 2016/2284, which mandates that every EU member country must reduce the emission of air pollutants, including ammonia (EU Directive, 2016). Ferket et al. (2002) noted that ammonia emission is linked to nitrogen utilization and the composition of intestinal microflora. Supplementation of probiotics in livestock diets has been shown to stimulate endogenous enzyme production, thereby enhancing nutrient digestion and absorption (Payling et al., 2017). Synbiotics, through various mechanisms, modulate the gut microbiome community, influencing the microbial composition of faeces and the volume of gases released from manure (Raninen et al., 2011). This was confirmed by Park et al. (2016), whose study demonstrated that supplementation with *E. faecium* shifted the fecal microbial composition, resulting in increased nitrogen retention and reduced nitrogen excretion. Consequently, this led to lower ammonia emissions from excreta and improved nitrogen digestibility, corroborating the earlier findings of Ferket et al. (2002). It is important to note, however, that while synbiotics have been confirmed to reduce nitrogen and methane emissions to the environment in livestock management, there remains a degree of inconsistency across studies. Some synbiotic combinations yield positive outcomes, while others report negative responses indicating that a lot of factors like the strain of the probiotics in the combination, the species of the animal, physiological states and other factors contributed to this inconsistencies. This highlights the need for further research to explore the specific mechanisms through which synbiotics influence livestock performance and environmental impact.

This paper therefore aims to give an overview of recent research on the effectiveness of synbiotic formulations—particularly those comprising *Bifidobacterium, Lactobacillus and Enterococcus species*—in poultry, swine and ruminants. By synthesizing findings from existing studies, the review will assess how these synbiotics influence gut health, growth performance, and disease resistance in each species. The review will also examine strain-specific effects to determine how individual microbial constituents and their interactions affect key outcomes such as nutrient absorption, immune modulation, and pathogen inhibition. Additionally, it provides insights into emerging technologies in natural growth promoters as sustainable alternatives to conventional antimicrobials.

2. Synbiotics

2.1. Mechanism of Action of Synbiotics

Synbiotics, a synergistic combination of prebiotics and probiotics, offer enhanced health benefits by simultaneously modulating the gut microbiota and promoting host wellbeing. To fully understand the synergistic or complementary effects of synbiotic preparations, it is essential to explore both components mechanisms of action. Probiotics, being live microorganisms, must meet several critical selection criteria before incorporation into livestock diets. These include resistance to digestive tract conditions such as enzymatic activity, acidic pH, and bile salts. Additionally, the chosen probiotic strain must be recognized as safe (generally regarded as safe—GRAS status) and amenable to large-scale industrial production (Markowiak and Śliżewska, 2018). Prebiotics, on the other hand, should selectively stimulate beneficial microbes while simultaneously inhibiting the proliferation of pathogenic microbes.

The primary mechanism of prebiotic action involves selective stimulation of gut microorganisms through specific microbial enzymes that hydrolyze prebiotics into fermentable sugars, including acetate, propionate, and butyrate, which plays a critical role in maintaining gut barrier integrity, and also exhibit immunodulatory effects. This selective fermentation process provides probiotic strains with a competitive advantage, enhancing both their colonization and metabolic activity within the gastrointestinal tract.

Although significant advancements have been made regarding the incorporating of probiotics into livestock feed, the precise mechanisms through which these additives exert their effects have not been fully elucidated. The proposed mechanisms include competitive exclusion, bacterial antagonism, and immune system stimulation (Ohimain and Ofongo, 2012). As live microorganisms, probiotics exhibit competitive exclusion by occupying binding sites and utilizing nutrients that would otherwise be accessible to pathogenic microbes, thereby effectively preventing their colonization in the gut. Some probiotic strains also possess enzymatic capabilities that enable them to produce antimicrobial substances such as bacteriocins. These compounds, along with the ability of probiotics to reduce intestinal pH, contribute to the inhibition of pathogenic bacteria (Hume, 2011). In addition, probiotics engage in fermentation processes that result in the production of short-chain fatty acids (SCFAs). These SCFAs have been shown to upregulate host defense peptide gene expression. They inhibit bacterial metabolic activity at higher concentrations through a specific mechanism: small, non-ionized SCFA molecules permeate bacterial membranes and dissociate into protons and anions within the cytoplasm. The release of protons lowers intracellular pH, disrupting metabolic reactions, while the anions interfere with osmotic balance (Sunkara et al., 2012; Sun and O'Riordan, 2013).

In a complementary synbiotic, the probiotic and prebiotic components independently exert beneficial effects. For example, probiotics such as *Lactobacillus* and *Bifidobacterium* strains improve gut health through mechanisms like competitive exclusion of pathogens, production of antimicrobial substances such as bacteriocins, and modulation of the immune response. Simultaneously, prebiotics such as inulin or fructo-oligosaccharides (FOS) selectively stimulate the growth of beneficial microbes and suppress pathogenic enzymes by being fermented into short-chain fatty acids (SCFAs) like acetate, propionate, and butyrate, which support gut barrier integrity and exhibit immune-modulatory effects. In this case, both agents act independently but contribute to a common goal—improved intestinal function (Chan and Liu, 2022). In contrast, synergistic synbiotics are formulated such that the prebiotic specifically enhances the survival and colonization of the co-administered probiotic strain. This is achieved when the prebiotic serves as a direct energy source, metabolized by specific microbial enzymes possessed by the probiotic strain, leading to its preferential growth and activity in the gastrointestinal tract. This synergy enhances probiotic performance, SCFA production, and pathogen inhibition, resulting in amplified health benefits that are greater than the sum of individual effects (Markowiak and Śliżewska, 2018). Understanding these interactions is crucial for designing effective synbiotic formulations tailored for livestock, ensuring optimal gut health, immune modulation, and productivity.

2.2. Synbiotic Supplementation in Poultry

Synbiotics enhance poultry health by modulating intestinal microbiota, boosting immune response, and improving nutrient utilization, offering a holistic approach to reducing antibiotic reliance. Tavaniello et al. (2023) demonstrated that *in-ovo* administration of PoultryStar® solUS (containing *Bifidobacterium*, *Enterococcus*, *Lactobacillus*, and FOS) at 12 days incubation significantly reduced hatchability (85.4% at 2 mg/embryo; 80.6% at 3 mg) versus controls (94.5%), likely due to embryogenesis interference from early injection timing or dosage. Although early growth (0–14 days) was unaffected, the 2 mg group showed reduced body weight and daily gain mid-phase (15–36 days), while water-administered synbiotics post-hatch yielded a non-significant 7.3% numerical increase in final weight (56 days) compared with all the synbiotic treatments, this might have been a result of stress at the early stage of embryogenesis experienced by the broiler chicks. Contrastingly, Duan et al. (2021) reported no hatchability or growth difference using a different synbiotic (*L. plantarum* + Astragalus polysaccharides) injected later (day 18.5), with significantly improved feed intake, body weight, and feed conversion ratio (FCR), alongside enhanced immunity (elevated IL-2, IFN-γ, IgA), gut development, and microbiota shifts (↑ *Lactobacillus*/*Bifidobacterium*; ↓ *E. coli*). These divergent outcomes highlight the relevance of dosage, injection timing, and strain-specific efficacy, suggesting that mid-phase performance decline may reflect embryonic stress (Tavaniello et al., 2023), whereas results from Duan et al., 2021 underscore synbiotic benefits in layers. Hence, the need for correct standardization of process during the in–ovo treatment of chicks for enhanced benefit.

Synbiotics have been shown to have a positive impact on the growth and other production parameters in poultry. The resultant effect of a multi strain combination for instance seem to be significantly different from a mono strain combination, an assumption evidenced by the study conducted by Reuben et al., (2022), where the average body-weight gain (BWG) of a mono strain combination was lower than the average weight of a multi strain combination highlighting the complementary action of these microbes on poultry performance. Although the mono-strain synbiotic showed a significant difference compared to the positive and negative control, the overall effect of the multi-strain treatment compared to other treatment was significantly higher and better. This also confirmed this study conducted by Attia et al., (2023) where *L.acidophilus* with mannan oligosaccharides (MOS) showed no effect on the growth parameters in poultry, whereas several other studies confirmed a significant improvement when different strains of probiotics were used together in synbiotic combination. In contrast, a mono-strain synbiotic (Biomin® IMBO, containing *Enterococcus* and immune-modulating substances) significantly improved ($P<0.05$) body weight and weight gain in broilers, suggesting that the effectiveness of mono-strain synbiotics may depend on the specific microbial strain involved.

Synbiotics have also demonstrated the capacity to counteract the negative effects of heat stress in poultry by modulating gut microbiota, reducing oxidative stress and inflammation, and supporting immune and skeletal health. In a study by Hu et al. (2022), a synbiotic containing *Enterococcus*, *Lactobacillus*, and FOS was compared to the antibiotic bacitracin methylene disalicylate (BMD) under both normal and heat-stressed conditions. While traditional antibiotic growth promoters like bacitracin methylene disalicylate (BMD) show benefits under normal conditions, they fail to mitigate heat stress effects and may even exacerbate oxidative stress. In contrast, synbiotics demonstrate remarkable efficacy in heat-stressed broilers through multiple protective mechanisms. Research shows synbiotics improve weight gain during heat exposure by enhancing the antioxidant system, as evidenced by increased superoxide dismutase activity and reduced oxidative damage. They modulate immune responses by lowering pro-inflammatory cytokines like IL-6 while boosting protective immunoglobulins, particularly IgY. Synbiotics also maintain gut barrier integrity, preventing pathogen translocation and subsequent issues like diarrhea and footpad dermatitis. Unlike antibiotics, they preserve beneficial gut microbiota balance while improving skeletal health and leg strength, as shown by better gait scores and longer standing times in latency-to-lie tests. These multifaceted benefits make synbiotics a superior alternative to antibiotics in heat stress conditions, offering a sustainable solution that enhances both productivity and animal welfare in tropical and subtropical poultry production systems.

In the research conducted by Oliveira et al., (2024) synbiotic (containing *Enterococcucs, lactobacillus* and *bifidobacterium*, + mannase and glucan oligosaccharides) compared to Zinc Bacitracin antibiotics supplementation in post-peak laying hens (70-90 weeks) demonstrated nuanced but important effects on core production parameters. While the study found no significant ($p > 0.05$) improvements in standard performance metrics like egg production, feed intake, or feed conversion ratio confirming the study by Najafabadi et al. (2017), that observed limited effect of prebiotics in aged layers due to their already stable digestive physiology and microbiota, it revealed several valuable benefits that could influence commercial layer operations. The most notable impact was on egg quality, with synbiotic-fed hens producing eggs with more intensely pigmented yolks (higher a* and b* values representing the intensity of the red colour and yellow colour respectively for measuring the yolk colour at post peak laying phase) (compared to control groups, likely due to enhanced carotenoid absorption - a critical factor for consumer preference in many markets. Nutrient digestibility analysis showed synbiotics improved apparent metabolizable energy (AME) and crude protein digestibility (CPAMC), suggesting better nutrient utilization efficiency in older hens. Although not statistically significant, there was a trend toward improved shell thickness in synbiotic groups, potentially indicating better calcium metabolism. These findings suggest that while synbiotics may not boost quantitative production in stable, high-health environments, they offer qualitative advantages in egg quality and nutrient utilization that could be particularly valuable for extending the productive lifespan of aging flocks or meeting premium market demands. The results position synbiotics as a viable antibiotic-free alternative for maintaining egg quality and hen health in late production cycles, though their benefits may be more pronounced under stress conditions or in younger birds.

The use of synbiotics in turkey production has gained increasing attention as a sustainable strategy to enhance gut health, improve growth performance, and strengthen immune function, especially in the face of modern challenges such as antibiotic restrictions and environmental stressors. This is confirmed through the study conducted by Lipiński et al., (2021) which demonstrated that dietary supplementation with synbiotics (containing various lactobacillus strains and inulin at 0.5g/kg) significantly improved growth performance in turkeys. Compared to the control group, birds fed synbiotics exhibited higher final body weight (BW), lower feed conversion ratio (FCR), and improved European Production Efficiency Factor (EPEF) ($P \leq 0.5$). Notably, synbiotic supplementation reduced mortality rates, with the lowest mortality observed in the S1 synbiotic group. Synbiotics also positively influenced immune function, as evidenced by increased serum lysozyme activity and gamma-globulin levels, along with reduced ceruloplasmin activity, indicating an enhanced immune response and reduced oxidative stress (Alloui et al. 2013; Min et al. 2016). In the gastrointestinal tract, synbiotics lowered digesta pH in the crop and intestines, which may inhibit pathogenic bacteria and improve nutrient absorption. Despite these changes, villus height and crypt depth remained unaffected, indicating that synbiotics enhance gut function without altering intestinal morphology. However, synbiotics had no significant impact on carcass quality, dressing percentage, or breast muscle composition, confirming the result by (Sarangi et al., 2016; Abdel-Wareth et al. 2018; Tavaniello et al. 2019) suggesting their benefits are primarily metabolic rather than structural and indicating that the additives did not negatively affect meat quality

2.3. Synbiotic Supplementation in Swine

In regions where the swine industry is flourishing, there has been a growing interest in exploring natural alternatives to address the increasing concerns around antibiotic resistance and food safety—issues that directly impact both farmers and consumers. Newborn piglets are especially vulnerable to bacterial infections, primarily digestive and respiratory illnesses like enteritis and pneumonia, which can lead to substantial economic losses. Additionally, meat quality remains a major concern, particularly due to lipid oxidation during storage, which may result in contamination with harmful substances (Popova, 2017). In this context, synbiotics have emerged as a promising natural intervention. Research focused on post-weaning dietary strategies has consistently shown that synbiotics can positively influence weight gain and intestinal morphology, along with key performance metrics such as average daily gain (ADG), feed conversion ratio (FCR), and carcass yield. For instance, Zhu et al. (2023) reported that sow-offspring synbiotic supplementation led to improved growth performance during the 95–125 day period, with notable up regulation of genes related to muscle hypertrophy, such as MyoG and Myf5. These interventions also impacted meat quality traits like drip loss, cooking yield, and shear force, while enhancing muscle redness and reducing water loss—factors linked to better sensory properties and shelf-life.

One overlooked advantage of synbiotics is their ability to improve the oxidative stability of pork. Lipid oxidation significantly affects meat quality and safety, especially during storage. A study by Saracila et al. (2021) found that a synbiotic containing *Enterococcus faecium* and inulin reduced thiobarbituric acid reactive substances (TBARS) in refrigerated shoulder and ham samples, indicating delayed lipid peroxidation. This effect may be mediated by metabolites derived from the gut microbiota with systemic antioxidant activities. Furthermore, synbiotics have shown potential in modulating the lipid profile and energy metabolism in skeletal muscles. Zhu et al. (2024) observed that supplementation altered fatty acid composition, increased intramuscular fat, and upregulated genes related to lipid mobilization—such as ATGL, HSL, and CPT-1. These molecular modifications improved both the flavor and nutritional value of pork, as evidenced by elevated polyunsaturated fatty acid (PUFA) content in muscle tissue.

Recent studies have also expanded their focus to maternal dietary strategies, particularly during gestation and lactation, to improve piglet health post-weaning. Maternal nutrition plays a crucial role in shaping the gut microbiota and systemic immunity of offspring. Zhu et al. (2022) demonstrated that feeding synbiotics to sows during gestation and lactation altered the colonic microbiota and metabolome of their piglets. The piglets showed higher levels of beneficial bacteria like *Faecalibacterium* and *Roseburia*, along with elevated short-chain fatty acids (SCFAs) known to support gut epithelial integrity and immune function. Moreover, synbiotic supplementation lowered levels of harmful metabolites such as skatole and enhanced antioxidant capacity in weaned piglets—indicative of early-life microbial programming with lasting health and productivity implications. Multi-omics analyses have revealed that synbiotic use reshapes colonic microbial communities, increasing the abundance of phyla such as *Firmicutes, Actinobacteria,* and *Verrucomicrobia*, while modulating metabolic outputs like beta-sitosterol, guanidoacetic acid, and indole derivatives, all of which impact systemic metabolism and muscle physiology (Zhu et al., 2024).

Synbiotics that incorporate *Lactobacillus*, *Bifidobacterium*, and *Enterococcus* strains have been studies to check their effect as multifunctional feed additives capable of preventing colonization by harmful pathogens. For instance, Rodríguez-Sorrento et al. (2020, 2021) and Luo et al. (2024) explored the efficacy of synbiotics against pathogens such as *Salmonella*, enterotoxigenic *Escherichia coli* F4 (ETEC F4), and porcine epidemic diarrhea virus (PEDV). One study evaluated a synbiotic combination of *Lactobacillus rhamnosus* HN001, *Bifidobacterium infantis* CECT 7210, and inulin/oligofructose against *Salmonella Typhimurium*. Interestingly, while the individual components showed beneficial effects, the synbiotic combination did not yield synergistic benefits and, in some cases, worsened outcomes. The probiotic alone led to significant pathogen clearance (65% of piglets tested negative by day 7), enhanced intestinal morphology, and faster recovery, while the prebiotic alone also reduced colonization and modulated immune responses. However, the synbiotic group exhibited growth impairment, worsened gut damage, and no reduction in pathogen load.

Similarly, another study assessed the efficacy of *B. infantis* and *L. rhamnosus*, a prebiotic (galacto-oligosaccharides, GOS), and their combination against

ETEC F4 in piglets. The probiotic group showed the best outcomes in terms of pathogen clearance, growth performance, and reduced inflammation. The prebiotic group also supported recovery, though with lesser efficacy. The synbiotic group, however, experienced poorer performance post-infection, including higher inflammation and slower weight recovery. Interestingly, the effectiveness of the synbiotic was influenced by genetic factors such as the MUC4 polymorphism, with susceptible piglets showing worse outcomes and altered fermentation patterns. These findings emphasize the importance of strain-specific and host-dependent responses in designing gut health interventions for swine.

In another study, piglets supplemented with 0.1% synbiotic (a combination of *Saccharomyces cerevisiae*, *Lactobacillus*, *Bacillus subtilis*, β-glucan, and mannan oligosaccharide) showed improved growth and nutrient digestibility under normal conditions. Prior to PEDV infection, supplementation enhanced body weight, ADG, and feed efficiency, and increased the digestibility of crude protein, energy, and dry matter. Post-infection, the synbiotic group exhibited reduced viral loads, lower diarrhea incidence, and better intestinal integrity, as indicated by increased expression of tight junction proteins and mucins, and reduced serum diamine oxidase activity. The immune response was also modulated, with increased levels of anti-inflammatory cytokines and immune factors and suppressed pro-inflammatory markers. Notably, a higher dose (0.2%) was less effective, suggesting that the underlying mechanism of action of the synbiotics needs to be determined.

In conclusion, synbiotics incorporating *Lactobacillus*, *Bifidobacterium*, and *Enterococcus* hold considerable promise in swine nutrition by enhancing gut health, boosting immunity, improving growth and meat quality, and reducing oxidative stress. However, their efficacy is influenced by factors such as dosage, strain specificity, host genetics, and microbial interactions.

2.4. Synbiotic Supplementation in Ruminants

Extensive research across ruminant species demonstrates the wide-ranging benefits of synbiotics, from optimizing growth performance and nutrient utilization to enhancing gut health, immune function, and even reproductive efficiency. Recent studies underscore the profound impact of synbiotics on ruminant productivity. In a 90-day trial with male Zell lambs, Saravani et al. (2025) demonstrated that the synbiotic *Biomin IMBO* (containing *Enterococcus faecium* and inulin) significantly improved final body weight, average daily gain, and feed efficiency (P<0.05). These benefits are reported to be likely driven by increased populations of cellulose-splitting bacteria in the rumen, which enhance fiber digestion and dry matter intake (Ghazanfar et al., 2015). Notably, the synergistic effects of synbiotics were further confirmed by Ndegwa et al. (2024), who observed no significant improvements in pre-weaned goats supplemented with probiotics alone, emphasizing the critical role of combining probiotics with prebiotics for optimal results. Beyond growth metrics, synbiotic-fed lambs exhibited improved blood lipid profiles and reduced urea nitrogen levels, reflecting enhanced nutrient partitioning. Carcass analysis revealed tangible economic benefits, including higher hot and cold carcass yields and increased proportions of premium cuts like the thigh and shoulder. These outcomes illustrate how synbiotics can simultaneously boost production efficiency and meat marketability. The benefits of synbiotics extend to gut microbiota modulation and immune system fortification. Sharma et al. (2023) documented the transformative effects of a synbiotic (150ml, 100ml and 50ml *Lactobacillus plantarum* CRD-7 + 3g, 6g and 9g fructooligosaccharides) respectively in Murrah buffalo calves. The optimal dose (6 g FOS + 100 mL probiotics) not only enhanced crude protein digestibility and daily weight gain but also reshaped the gut ecosystem, promoting beneficial *Lactobacilli* and *Bifidobacterium* while reducing fecal ammonia—a marker of protein fermentation. Critically, synbiotic supplementation reduced diarrhea incidence and strengthened both cellular and humoral immune responses, highlighting its potential to establish a resilient gut-immune axis in early life. These findings align with Xu et al. (2025), who reported that synbiotics (*Lactobacillus* LPN-1 + isomaltose-oligosaccharide) reprogrammed neonatal development in Hu lambs, resulting in a 48.3% increase in average daily gain and improved rumen and spleen development. Additionally, synbiotic use significantly reduced antibiotic dependency, supporting global antimicrobial stewardship efforts. Importantly, the role of synbiotics extends beyond growth, immunity, and nutrient utilization, with emerging evidence highlighting their potential to enhance reproductive performance in ruminants. A pioneering study by Al-Sobayil et al. (2010) demonstrated that a synbiotic blend containing *Lactobacillus acidophilus*, *Streptococcus thermophilus*, *Bifidobacterium bifidum*, and prebiotics from fenugreek, lupin, and citrus significantly improved reproductive outcomes in Najdi ewes. While estrus expression remained similar across groups, synbiotic-treated ewes showed a shortened interval between Controlled internal drug release (CIDR) removal and estrus onset (52–60 hours vs. 60 hours), and pregnancy rates increased markedly from 56% in controls to 78% in both low- and high-dose groups. Although prolificacy declined slightly (1.0 vs. 1.4 lambs/ewe in control), this was compensated by a 62% increase in lamb birth weight (4.920 g vs. 3.030 g in control), resulting in a significantly higher total lamb yield per ewe (P<0.05). Progesterone levels during gestation were 61% higher in treated ewes compared to baseline, suggesting enhanced luteal activity potentially driven by improved nutrient absorption and metabolic signaling. The observed benefits are likely due to the synergistic actions of synbiotic components: prebiotics such as fenugreek, lupin, and citrus oligofructose support gut mucosal health and microbial stability—with fenugreek's diosgenin possibly stimulating hormonal activity—while probiotics enhance immune function, inhibit pathogens, and may elevate IGF-1 levels associated with fetal growth (Mir et al.,1997; Rautava, 2007). Additionally, short-chain fatty acids (SCFAs) produced through fermentation may support progesterone synthesis via cytokine modulation. Collectively, these findings reinforce the multifaceted value of synbiotics in livestock, not only improving productivity and health but also advancing reproductive efficiency.

3. Conclusion

While this review has specifically examined the role of *Enterococcus, Bifidobacterium*, and *Lactobacillus*-based synbiotics in poultry, swine, and ruminant nutrition, it is important to note that the scope of synbiotic application in animal nutrition extends far beyond these strains. Numerous formulations, combining various probiotics, prebiotics, enzymes, plant extracts, and functional compounds, are being explored as potential tools to optimize animal performance. Emerging formulations like SYMBIOVEBA®, which combines probiotics with enzymes and plant extracts, demonstrate promising though variable effects on milk composition and udder health, as shown by Dadda et al. (2025). The synbiotic showed promise in reducing subclinical mastitis, as indicated by changes in milk parameters and California Mastitis Test (CMT) scores. Furthermore, emerging alternatives such as postbiotics and prophybiotics offer promising complementary or standalone approaches the growing field of microbiome interventions - presents new opportunities that should be explored in combination with synbiotics to enhance their benefits while mitigating potential limitations. With the advancement of animal nutrition and biotechnology, large-scale longitudinal studies, phenomics, genomic and multi-omics approaches will be essential to fully understand the mechanisms of action and long-term impacts of these interventions. As the livestock industry continues to seek sustainable alternatives to antibiotics, synbiotics and related microbiome modulators offer considerable promise, but their successful implementation will require continued innovation, rigorous scientific validation, and careful consideration of practical applications in diverse production systems. In addition microbe to microbe interaction studies are important to enhance synergistic mechanisms. Future research should focus not only on optimizing these tools but also on integrating them into comprehensive precision nutrition strategies that balance productivity, animal welfare, and environmental sustainability

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	B.M.	G.A.I.	U.Ş.
C	30	40	30
D	30	40	30
S	30	40	30
DCP	30	40	30
DAI	30	40	30
L	30	40	30
W	30	40	30
CR	30	40	30
SR	30	40	30
PM	30	40	30
FA	30	40	30

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declare that there is no conflict of interest.

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