Supplemental Table S1: Probiotics and Prebiotics: Mechanisms of Action for Gut Health in Monogastric Livestock

Component	Type	Source/Examples	Mechanism of Action	Effect on Gut Health	Impact on Livestock Performance	Potential Risks/Considerations	References
Probiotics	Viable, non-pathogenic microbes	Lactobacillus, Bifidobacterium species, yeast (e.g., Saccharomyces boulardii)	Enhance the growth of beneficial bacteria, compete with pathogens for space and resources, release antimicrobial compounds (e.g., lactic acid, bacteriocins)	Maintain gut microbiota balance, improve intestinal barrier integrity, stimulate mucus production, reduce pathogen load	Improved growth rate, nutrient utilization, immune response, and disease resistance	Misuse or over-supplementation could disrupt the natural microbiota or cause imbalances	[192]
Lactobacillus Species	Lactic acid bacteria	Fermented foods, supplements	Produce lactic acid to maintain acidic pH in the gut, inhibit growth of harmful bacteria, promote SCFAs production	Lower gut pH, inhibit pathogenic bacteria, stimulate gut health by producing SCFAs (e.g., butyric acid)	Enhanced growth, better feed conversion, reduced pathogenic bacteria, improved immunity	Some strains may not survive in the gastrointestinal tract under certain conditions	[193]
Bifidobacterium Species	Beneficial bacteria	Fermented products, supplements	Metabolize carbohydrates into SCFAs, enhance growth of beneficial bacteria, and modulate immune responses	Improve gut barrier function, increase beneficial microbiota, support immune system function	Better growth, enhanced feed conversion, and immune system improvement	Can cause digestive upset if administered in excess	[194]

Prebiotics	Non-digestible food ingredients	Oligosaccharides, Inulin, Fructooligosaccharides (FOS)	Serve as a food source for beneficial bacteria, selectively enhance the growth of good bacteria, and inhibit pathogen growth	Improve gut microbiota composition, increase SCFAs production, lower gut pH, and enhance gut barrier function	Better digestion, nutrient absorption, improved immune function, enhanced productivity	High doses may cause digestive discomfort, bloating, or flatulence	[195]
Oligosaccharides	Short-chain sugar molecules	Legumes, beans, chicory, garlic, onions	Not digestible in upper GI tract, reach colon where they are fermented by beneficial bacteria	Stimulate growth of Bifidobacterium, increase SCFAs, reduce gut pH, and inhibit pathogenic bacteria	Enhanced nutrient absorption, improved feed conversion, reduced disease susceptibility	May cause discomfort in high quantities or alter gut microbiota composition	[196]
Inulin	Fructan polysaccharide	Chicory, Jerusalem artichokes, garlic, onion	Stimulates Bifidobacterium growth, increases SCFAs levels, and reduces gut pH to limit pathogen growth	Increase in beneficial gut bacteria, improved gut barrier function, enhanced digestion, and immunity	Improved nutrient utilization, enhanced growth rates, and better feed conversion	It can cause bloating or flatulence when administered in excess	197]
Synbiotics	A combination of probiotics and prebiotics	Combination of probiotics (e.g., Lactobacillus, Bifidobacterium) and prebiotics (e.g., FOS, inulin)	Provide both beneficial microorganisms and food sources for these microbes, enhancing the synbiotic relationship	Improve gut microbiota, enhance digestion, stimulate immune response, and reinforce gut barrier integrity	Improved growth, nutrient absorption, better immunity, and reduced antibiotic use	Strain/dose mismatch can limit effectiveness; may cause gastrointestinal upset	[79]

Overall Effects of Synbiotics	Combined effect of probiotics and prebiotics	A combination of various beneficial probiotics and prebiotics	Enhance gut health synergistically by combining the benefits of both probiotics and prebiotics, improving overall gut function	Balanced gut microbiome, reduced pathogenic microorganisms, better nutrient absorption, enhanced immune function	Increased productivity, improved growth rates, better feed conversion, reduced antibiotic usage	May have varying effects based on livestock species, strain, and diet composition	[70,198]

Supplementary Table S2: Impact of Gut Health on Nutrient Absorption and Utilization in Monogastric Livestock

Factor	Role of Gut Health/Probiotics/Prebiotics	Mechanism of Action	Impact on Nutrient Utilization	Effect on Animal Performance	Key Studies/Findings
Gut Microbiota	Natural gut flora of monogastric animals	Breaks down larger nutrient particles into smaller molecules, releases SCFAs like butyrate, and supports the function of nutrient transporter genes	Enhances protein, fat, and carbohydrate digestion and absorption through improved microbial activity	Improved nutrient solubility, absorption, and energy utilization for metabolism and growth	[100,101]
Protein Metabolism	Probiotics and prebiotics (e.g., Lactobacillus, Bifidobacterium)	Enhances the breakdown of proteins into peptides and amino acids, and increases proteolytic enzyme production by beneficial bacteria	Improved protein digestion and amino acid absorption, aiding in muscle growth and tissue accretion	Increased growth rates, better muscle development, improved feed conversion ratio (FCR)	[101,103, 104]
Fat Metabolism	Probiotics (Lactobacillus, Bifidobacterium)	Microbial fermentation of undigested carbohydrates to produce SCFAs, which aid in fat metabolism and reduce fat accumulation	Improved lipid digestion, increased fat utilization for energy, and better body composition	Enhanced fat utilization for energy production, better body composition, and increased energy availability for growth	[104,105,106]

Carbohydrate Metabolism	Probiotics and prebiotics (e.g., inulin, oligosaccharides)	Microbial breakdown of complex carbohydrates into simple sugars that can be absorbed by the gut cells	Increased digestion of carbohydrates, improved glucose absorption, and energy utilization	Improved feed intake, increased growth rates, and better feed conversion	[101,102,103]
Gut Barrier Function	Probiotics (e.g., Lactobacillus, Bifidobacterium)	Stimulate mucus and tight junction protein production, strengthen the epithelial barrier to pathogens and toxins	Increased intestinal barrier integrity, reduced pathogen invasion, and inflammation	Improved disease resistance, reduced incidence of gastrointestinal diseases (e.g., diarrhea), better growth, and feed conversion	[120,121]
Feed Conversion Efficiency	Probiotics, prebiotics (e.g., inulin, oligosaccharides)	Increased nutrient solubility and absorption through enhanced gut microbial activity	More efficient nutrient digestion and absorption, improved feed conversion ratio (FCR)	Increased growth rate, less feed required for weight gain, reduced feed costs	[111]
Growth Rate	Probiotics, prebiotics, synbiotics	Enhanced nutrient absorption, improved protein, fat, and carbohydrate metabolism, reduction of gastrointestinal disorders	Accelerated weight gain, increased muscle growth, improved overall productivity	Higher weight gain, improved growth performance, reduced time to market	[108,109]
Stress Tolerance	Probiotics and gut microbiota stability	Modulation of immune responses, reduction of cortisol (stress hormone), control of oxidative stress and inflammation	Reduced negative impact of stress on digestion and growth, improved immune response	Improved health, better growth rates, enhanced ability to tolerate environmental stress, improved feed intake, and FCR	[48,101]
Disease Resistance	Probiotics and prebiotics (e.g., Lactobacillus, Bifidobacterium)	Strengthen gut microbiota, enhance gut barrier function, improve immune system responses	Reduced pathogen load, improved immune system activity, and reduced gastrointestinal diseases	Better health, fewer diseases, improved feed conversion, better weight gain, reduced need for antibiotics	[18,19]
Meat Quality	Probiotics and prebiotics	Improve nutrient digestion and	Enhanced lean meat yield, improved quality	Increased quality and yield of lean meat,	[128]

		absorption, reduce fat content, and increase lean meat yield	of meat due to better nutrient utilization	better fat-to-muscle ratio in pigs and poultry	
Overall Productivity	Probiotics, prebiotics, synbiotics	Optimized gut health leads to better nutrient utilization, reduced gastrointestinal disorders, and enhanced immune function	Increased feed efficiency, faster growth rates, improved overall performance	Improved productivity, reduced feed costs, and better profitability in livestock production	[130,131]

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