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REVIEW

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Probiotics in Ruminants: A Comprehensive Review of Health, Production and Future Frontiers

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Abstract

The increasing human population is inherently linked to a rising need for both plant and animal-derived food. As a result, scientists look for ways to increase food production efficiency while reducing expenses and maintaining strict quality and safety standards for both human consumption and environmental sustainability. Nevertheless, using antibiotics in animal production comes with a number of challenges. The main concern related to the use of antibiotics is antimicrobial resistance. Probiotics, on the other hand, provide livestock with nutritional and health benefits when given in the right amounts and are becoming a popular, safe, and sustainable substitute for antibiotics. As we explore the potential of individual probiotic strains, we highlight their unique contributions and emphasize how they can help optimize milk production, improve nutrient digestibility, build a robust gut microbiota, and stimulate growth. Probiotics impact the growth parameters, which illustrates their potential as growth promoters. Additionally, their immunomodulatory effects support the natural defence mechanisms of ruminants. This review provides valuable insights into the various applications of probiotics in enhancing the overall well-being and productivity of ruminant livestock. This review highlights the many advantages of probiotics. It presents them as essential components in improving the general health and productivity of ruminant livestock through a thorough literature synthesis.

KEYWORDS

Probiotics; Ruminant Nutrition: Livestock; Production; Immunity

Conflict of Interest

The authors declare that the manuscript was formulated in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Authors Contribution

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

INTRODUCTION

The rapidly growing human population poses a serious threat to global food security, particularly in developing countries such as Southeast Asia and Africa, where animal proteins are a crucial source of protein. The livestock industry is a significant player in these regions, with farmers relying on livestock for their livelihoods (Grace, 2012). Antibiotics are often used as antimicrobial growth promoters (AGPs) in the veterinary industries to encounter the increased demand for fish and meat production (Li et al., 2020). However, using antibiotics in feed can result to antimicrobial resistance in the pathogenic microbes (Deng et al., 2020a, 2020b), which can pose a threat to consumer health through the potential contamination of animal products. To address this issue, the European Union banned the non-therapeutic antibiotics usage in 2006, promoting livestock diets and preventing diseases (Arowolo and He, 2018).

The utilization of antibiotics in animal feed resulted to the consumer preferences for natural animal products, creating a need for alternative feed additives. Probiotics, initially defined as the opposite of antibiotics by Lilly and Stillwell (1965), have been found to improve animal health and growth, making them a valuable solution to increase the production of milk, meat and fish without any adverse effects. In animal feed, the usage of probiotics has increased due to its positive role on nutrition and health in various livestock species. Additionally, probiotics have been demonstrated to lessen the presence of foodborne microorganisms, such as *Salmonella*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Clostridium perfringens*, and *Escherichia coli*, which can have significant economic implications for the dairy industry. Probiotics can also be used in dairy cows and other livestock to maintain their general health, immunity, and nutrient requirements, making them a promising solution for long-term sustainability in the industry. With an emphasis on probiotics application in ruminants, this review examines the impact of probiotics on ruminant health, growth, productivity, and product quality.

PROBIOTICS SPECIES IN RUMINANT HEALTH

In 1965, Lilly and Stillwell coined the term “Probiotic” which described the secretory product of one living organism that regulate the growth of other (Gupta et al., 2009). Although In 1908, Elie Metchnikoff already proposed the theory that the live microorganisms in the sour milk products like yoghurt is the reason for the longevity of the Bulgarian people, as it inhibits the pathogenic organisms in the GIT (Metchnikoff, 1908). Probiotics are live microbes that include various species of bacteria, microalgae, bacteriophages or yeasts which are not harmful to the host but help in stabilizing the host microorganisms, thereby serving several positive impacts to the animal. However, these various strains of microbes are host-specific to serve these benefits (Williams et al., 2010). Even though there are several strains, the probiotic species mainly used are Lactobacillus, Streptococcus, Bifidobacterium, Lactococcus, Enterococcus, Saccharomyces, *Aspergillus oryzae*, and *Candida pintolopesii* in farm animals (Lambo et al., 2021). Among these various probiotic strains, Yeasts have more beneficiary role in ruminant health than bacterial probiotic organisms. In contrast, bacterial strains have more benefits in non-ruminant animals than yeasts (Mahesh et al., 2020).

TABLE 1: COMMONLY USED PROBIOTIC MICROORGANISM IN RUMINANTS

Genus	Species	Destination	Reference
Lactobacillus	*L. acidophilus*	Calves Dairy cows Lactating cows Goats	Adjei-Fremah et al., 2018 Gyenai et al., 2016 Vibhute et al., 2011
	L. reuteri	Goats	Gyenai et al., 2016
	L. plantarum	Dairy cows	Xu et al., 2017
	L. delbrueckii subsp. bulgaricus	Calves	Markowiak et al., 2018
	L. casei	Calves Dairy cows	Hasunuma et al., 2011 Xu et al., 2017
	L. rhamnosus	Goats Cattle	Markowiak et al., 2018 Gyenai et al., 2016
	L. salivarius	Goats	Chiofalo et al., 2004
Enterococcus	*E. faecium*	Dairy cows Goats	Adjei-Fremah et al., 2017 Gyenai et al., 2016
Lactococcus	*L. lactis*	Cattle	Markowiak et al., 2018
	B. breve	Goats	Gyenai et al., 2016
	B. longum	Goats	Gyenai et al., 2016
	B. bifidum	Calves	Markowiak et al., 2018
Bacillus	*B. licheniformis*	Sheep	Kritas et al., 2006
	B. subtilis	Sheep	Kritas et al., 2006
Yeast and fungi a) Aspergillus	*Aspergillus oryzae*	Dairy cows Goats	Ekwemalor et al., 2017 Adjei-Fremah et al., 2018 Daşkiran et al., (2012)

b) Saccharomyces	S. boulardii	Lactating cows	Vibhute et al., 2011
	Saccharomyces cerevisiae	Dairy cows	Adjei-Fremah et al., 2018

DIGESTIVE HARMONY: PROBIOTICS AND GUT HEALTH

The plant diet of ruminants mainly consists of complex carbohydrates like hemicellulose, cellulose, and lignin that cannot be degraded by gastric enzymes normally. These fibres can only be degraded by various cellulolytic organisms in the rumen. Probiotics helps in improving the development of these organisms thereby enhances the fibre degradation, rumen digestibility and better feed intake (Reuben et al., 2022). Live yeast addition in the ruminant diet is found to enhance the rumen pH, which is more suitable for the colonization of the cellulolytic bacteria. Several studies (Khalid et al., 2011; Chaucheyras-Durand et al., 2012; Bahari, 2017) revealed that probiotics also reduces the incidence of ruminal acidosis, increases the feed efficiency, dry matter intake, and the flow of nitrogen into the lower GIT. In 2016, KS Retta also reported the involvement of probiotics in increasing the nitrogen passage to the intestinal tract, growth of adult rumen microbes, rumen fermentation process and also its role in supporting the microbes that provides the proteins, vitamins and organic acids to the host. Probiotics found to decrease the inter meal gap in lactating cows, increase the average daily weight gain in ruminants through better FCR, efficient utilization of nutrients, and increased nitrogen retention (Arowolo et al., 2018).

MILK PRODUCTION AND PROBIOTICS

Probiotics, which have been shown to positively affect the gut health, may be used to increase milk production. Research conducted by Desnoyers et al., 2009 has shown that milk quality and quantity can be enhanced by adding probiotics to feed. According to So et al., (2021), there is a reduced somatic cell count (SCC) and improvement of various physiological parameters like blood glucose, total volatile fatty acids, gross energy (GE), dry matter and fibre digestibility and metabolic energy intake (ME) when L. casei TH14 is supplemented in the cattle feed. A comparable finding has been confirmed by numerous studies (Peng et al., 2012; Moallem et al., 2009), showing that probiotic supplementation in dairy animals, raised milk yield with proper nutritional constituents of milk.

Yu et al., 1997 conducted an experiment which involved feeding cows steamed corn along with Aspergillus oryzae culture for 70 days and found that milk had higher proportion of Solids-Not-Fat, or SNF and protein. According to a study by Suntara et al., (2021b) on lactating Holstein cows, protein content in milk increased when *P. kudriavzevii* KKU20 and C. tropicalis KKU20 (Crabtree-negative yeast) was added to animal feed. Xie et al., (2019) reported similar findings, who found that higher milk and milk protein yields are mediated by rumen microbial crude protein. Additionally, the quantity of microbial crude protein increased because of the rumen's increased beneficial microbial population. Milk yield is influenced by the amount as well as the quality of metabolizable protein absorbed in the gut, which is then converted into milk protein by gut microorganisms that produce microbial crude protein (Nalla et al., 2022).

Likewise, Results from the study by Kritas et al., (2006) on sheep revealed that feed incorporated with Bacillus licheniformis and Bacillus subtilis bacterial strains as well as the YEA-SACC-1026 probiotic at the time of late gestation and milk feeding enhanced the milk fat and the protein content of milk, and brought up the body weight of lambs. Enterococcus faecalis, Saccharomyces cerevisiae, and Bacillus subtilis, increased the percentage of total solids in milk, protein and fat content of milk in lactating goats (Ma et al., 2020).

GROWTH PROMOTERS: PROBIOTICS IN RUMINANTS

Probiotics have a significant effect on growth performance of animals as they increase the growth rate and average weight gain by enhancing the digestibility and Feed Conversion Ratio (FCR) (Abd El-Tawab et al., 2016). Barki lambs supplemented with *Ruminococcus flavefaciens* in either powdered or liquid form had increased average daily weight gain (Hassan et al., 2020). According to Lesmeister et al., 2004, the supplementation of calf feed with yeast (*Saccharomyces cerevisiae*) resulted in improved total DM intake, daily hip height, daily hip width, and average daily body weight gain. IŞIK et al., (2004) found that adding 20 to 40 g of probiotics to milk and water during the first three months for Holstein calves resulted in a significant difference in daily live weight gain, with these animals remaining healthy without any diarrhoea. Additionally, Mudgal et al., (2010), discovered that adding probiotics (Lactobacillus acidophilus) to buffalo calves at a rate of 100 mg per day improved their growth rate, especially in the first month of age before rumen development. Sharma et al., (2016) reported that supplementation of probiotic (*Saccharomyces cerevisiae*) in buffalo calves resulted in increased growth rate in the first month and reduced the incidence of neonatal diarrhoea and mortality rate. The breakdown of simple carbohydrates, such as glucose, by Lactobacillus plantarum and the breakdown of carbohydrates and fibre through enzymes from Aspergillus oryzae can improve the feed conversion ratio and enhance animal performance and growth rate (Bahari, 2017).

ROLE OF PROBIOTICS IN MEAT QUALITY

Probiotics not only enhanced the growth and productivity of animals but also improved the quality of both fresh and processed meat products (Trabelsi et al., 2019). Probiotics use was shown to have a beneficial effect on meat quality by maintaining its colour, pH, Water Holding Capacity (WHC), texture, tenderness, and enhancing its antioxidant properties while reducing lipid oxidation (Al-Shawi et al., 2020). The degree of post-mortem pH decline affects the colour of meat (Matarneh et al., 2017). Typically, pH declines from 7.2 to a range of 5.6, but an abnormal drop can lead to meat which is dark, firm, and dry (DFD) with pH of more than 6.0. Conversely, increased carcass temperature can result in pale, soft, and exudative (PSE) meat through sudden pH drop. According to several studies (Zheng et al., 2014) (Pelicano et al., 2003) (Meng et al., 2010), using probiotics in feed improved meat colour stability and pH. Animals given probiotics had higher antioxidant capacity, less reactive oxygen species, and less lipid oxidation (Al-Shawi et al., 2020).

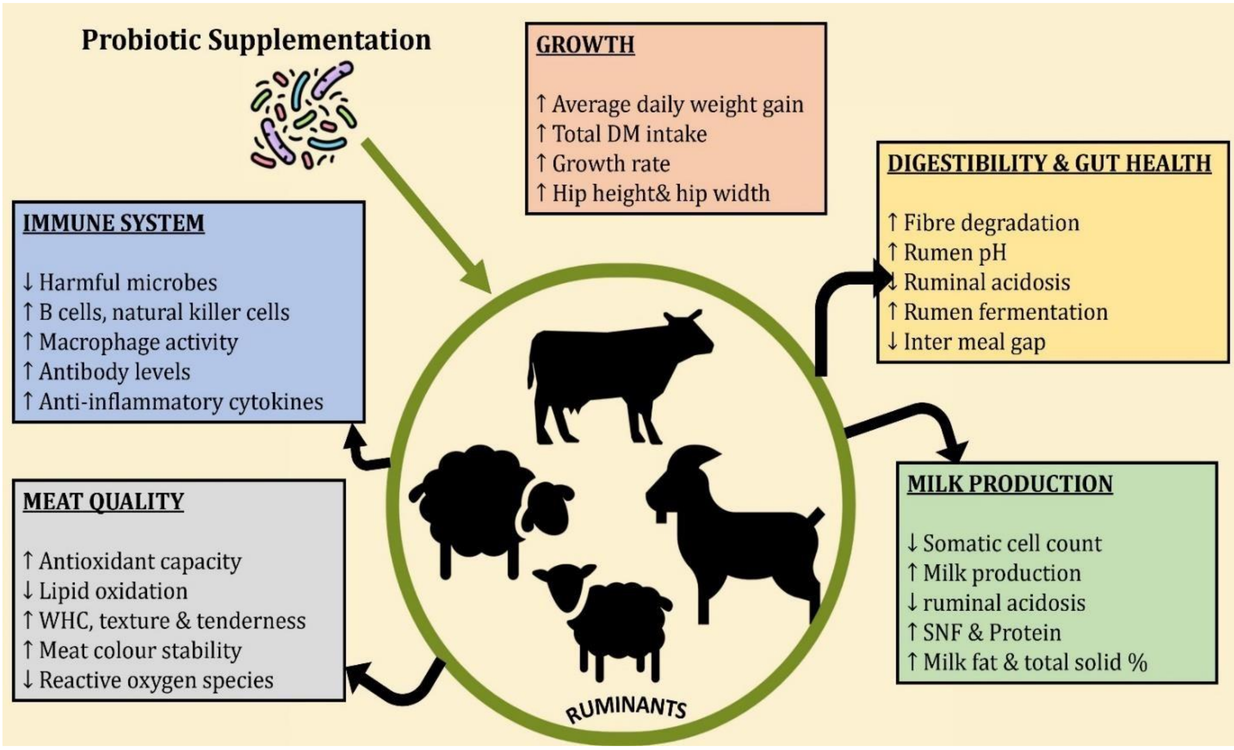

Fig 1: The role of probiotics supplementation in ruminant wellbeing (This figure was conceptualized based on the following references: Nalla et al., 2022; Anee et al., 2021; Al-Shawi et al., 2020)

PROBIOTICS AND IMMUNOMODULATORY ROLE

Probiotics have been proven to enhance immunity in ruminants owing to their immunostimulatory properties (Punetha et al., 2018). The regulation of immune system is by gene expression, stimulation of immune cells action, such as epithelial cells and dendritic cells, natural Killer T cells, and B cells, and controlling the signal process in host cells through the usage of probiotics (Begum et al., 2021). Cows with rumen acidosis can benefit by adding probiotics to their diet, which enhances their immune response and mitigates acidosis (Krehbiel et al., 2003). The pathogenic attacks including organic acids, defensins, bacteriocins, ethanol, diacetyl and carbon dioxide, can be reduced by antimicrobial peptides (AMPs), which are produced from the Lactic Acid Bacteria (LAB) (Liao and Nyachoti, 2017). Farm animals can benefit from the suppression of potentially harmful microbes through the utilization of organic acids, which includes formic acids, short-chain fatty acids, lactic acid (Anee et al., 2021). According to Nair et al., (2017), these organic acids affect the cytoplasmic membrane of the bacterial cell wall via protein synthesis and replication, resulting in destroying of pathogenic microorganisms.

According to several studies (Rizzo et al., 2015; Luongo et al., 2013), Lactobacillus bacteria, including Lactobacillus crispatus, Lactobacillus salivarius, Lactobacillus fermentum, and Lactobacillus gasseri, control the amounts of IL-6, IL-8, and IL-1 (pro- and anti-inflammatory interleukins) and help restore physiological balance in animals. Probiotic LAB has been shown to function as immune modulators by a number of studies (Suda et al., 2014; Suda et al., 2021; Shimazu et al., 2012; Kober et al., 2022). These studies have reported that, probiotic LAB enhances macrophage activity, raises local antibody levels, stimulates killer cells, lowers IL-4, IL-6, IL-8, MCP-1 and improves levels of IL-10, interferon (IFN)-γ, β, IL-1β, TGF-β (anti-inflammatory cytokines). Lactococcus lactis produces an antimicrobial peptide called Nisin. Mastitis caused by S. aureus can be treated in dairy cows by infusing nisin into the mammary glands (Cao et al., 2007). Furthermore, the health of the mammary glands is positively affected by teat spray containing Lactobacillus species, which also enhances the sphincter's function (Alawneh et al., 2020).

There are differences between probiotic strains. Unique contributions to ruminant immunity are shown by certain strains, such as Lactobacillus and Bifidobacterium. Enhancement of the immune system with probiotics can be made achievable by an understanding of strain-specific effects.

CONCLUSION

Probiotics have become an essential component in the nutrition of ruminants, as they play a significant role in enhancing production and promoting better animal health. There are numerous strains of probiotic organisms that are species-specific to the host animal and provide various health and economic benefits. The incorporation of probiotics in the ruminant diet can improve digestibility, feed efficiency, feed conversion ratio, feed intake, and nitrogen flow to the lower GIT, while also promoting healthy gut microflora and reducing methane emission and neonatal diarrhoea. Additionally, probiotics can increase body weight gain, growth rate, milk production, and boost the immune system, providing better protection against various infections. However, the proper mechanism of how it acts is still not fully clear, and some studies have shown insignificant changes after probiotic supplementation, which should be considered.

FUTURE PERSPECTIVES

Probiotics will perform a crucial role not only in the nutrition of ruminants but also in non-ruminants, poultry and aquatic species for upgrading the production and health in the coming years. While there is a diverse array of probiotic species available, future research is required for the better understanding of their positive and negative impacts in various species of animals. In future, studies should emphasize on elucidating the mode of action of these probiotic organisms for various beneficial roles. Additionally, it is essential to make probiotics commercially available at affordable prices and educate farmers about their critical role in animal diets.

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DECLARATION OF INTEREST

All authors declare that there exist no commercial or financial relationships that could, in any way, lead to a potential conflict of interest.

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