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Role of feed additives in animal nutrition and their effect on rumen metabolism: An overview

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Abstract

Feed additives are non-nutritive substances incorporated into animal diets to enhance nutrient utilization, improve performance and maintain health. They are broadly classified based on their mode of action into additives influencing feed stability, animal growth and metabolism, health, and consumer acceptance. Common categories include antibiotics, probiotics, prebiotics, enzymes, buffers, antioxidants, hormones, adsorbents, organic acids and flavouring agents. Antibiotics enhance growth and feed efficiency by modulating gut microflora, though their use is restricted due to antimicrobial resistance concerns. Probiotics and prebiotics promote beneficial microbial populations, improving gut health and immunity. Enzymes and buffers enhance digestibility and stabilize rumen function, while antioxidants prevent feed deterioration. Additional additives such as adsorbents mitigate toxins, and pigments improve product quality. Overall, feed additives play a crucial role in optimizing livestock productivity, feed efficiency, and product quality, while supporting sustainable and safe animal production systems.

Keywords: Animal productivity, feed additives, gut microflora, nutrient utilization, rumen metabolism

1. Introduction

Feed additives play a pivotal role in modern animal nutrition by enhancing the efficiency of feed utilization, improving animal health, and optimizing productive performance. With the increasing demand for animal-derived products and the need for sustainable livestock production, the use of feed additives has gained significant importance. These non-nutritive substances are incorporated into animal diets to influence various physiological and metabolic functions, particularly within the gastrointestinal tract, thereby improving nutrient availability and overall productivity.

Feed additives can be broadly classified based on their mode of action into categories such as those affecting feed stability, growth and metabolism, animal health, and consumer acceptance. A wide range of additives including antibiotics, probiotics, prebiotics, enzymes, buffers, antioxidants, and organic acids are commonly used in livestock feeding. These additives act through different mechanisms such as modulation of gut microflora, enhancement of digestive processes, stabilization of rumen pH, and prevention of oxidative deterioration of feed. Their inclusion in diets has been shown to improve feed efficiency, growth rate, and product quality in both ruminant and non-ruminant animals.

However, the use of certain feed additives, particularly antibiotic growth promoters and hormonal compounds, has raised concerns regarding antimicrobial resistance and residues in animal products. This has led to increased interest in safer and more sustainable alternatives such as probiotics, prebiotics, and plant-based additives. Therefore, a comprehensive understanding of the types, functions, and mechanisms of feed additives is essential for their judicious use in animal nutrition, ensuring enhanced productivity while maintaining food safety and environmental sustainability.

1.1 Classification of Feed Additives

According to the mode of action, feed additives are divided in four groups.

- Additives that influence feed stability, feed manufacturing and properties of feeds
- Additives that modify animal growth, feed efficiency, metabolism and performance
- Additives that modify animal health
- Additives that modify consumer acceptance

1. Additives that influence feed stability, feed manufacturing and properties of feeds

- Antifungal
- Antioxidant
- Pellet binders

2. Additives that modify animal growth, feed efficiency, metabolism and performance

- Feed flavour
- Digestion modifiers
 - Enzymes
 - Prebiotics
 - Buffers
 - Acidifiers
 - Ionophores
 - Antibloat compound
 - Isoacids
 - Salivation inducers
 - Probiotics
 - Defaunating agents

A) Metabolism modifiers

- Hormones
- Beta-adrenergic agent (repartitioning agents) Growth promotants
- Antibiotics
- Chemotherapeutic agents

3. Additives that modify animal health

- Drugs
- Immunomodulator

4. Additive that modify consumer acceptance

- Xanthophylls

2. Role of Feed Additives and Their Effect on Rumen Metabolism

2.1 Antibiotics

Antibiotics are chemical compounds produced by microorganisms such as fungi, and can also be synthesized in laboratories, which inhibit the growth of bacteria when administered in small quantities. They are widely used at therapeutic levels for the treatment of bacterial infections, while at subtherapeutic levels they are incorporated into animal feed as growth promoters to enhance production efficiency. Antibiotics improve nutrient utilization by modulating the gastrointestinal microflora through several mechanisms, including suppression of pathogenic bacteria, reduction of microbial competition for nutrients, stimulation of beneficial microbes that synthesize essential nutrients, and enhancement of the absorptive capacity of the intestinal wall. These effects enable animals to achieve production levels closer to their genetic potential.

The mode of action of antibiotics primarily involves interference with bacterial cellular metabolism. They can be classified into four major groups based on their mechanism: agents that inhibit bacterial cell wall synthesis causing cell lysis (e.g., avoparcin and flavomycin), inhibitors of protein

synthesis (e.g., tylosin and virginiamycin), inhibitors of DNA synthesis (e.g., nitrofurans and quinoxaline-N-oxides), and ionophore antibiotics. Ionophores, such as monensin sodium, disrupt the electrolyte balance of bacterial cells by facilitating potassium ion transport into the cell, leading to energy depletion, osmotic imbalance, and eventual cell rupture. Although the use of antibiotics in ruminants may be limited due to their dependence on rumen microbes, ionophore antibiotics have shown beneficial effects, particularly in animals fed low-roughage and high-concentrate diets. Monensin supplementation at 20–30 mg/kg feed has been reported to improve feed efficiency, while antibiotic growth promoters (AGPs) used in pig and poultry feeds at 20–40 mg/kg can enhance growth rate by 4–16% and improve feed conversion ratio by 2–7%. However, due to increasing concerns over antimicrobial resistance, the use of AGPs has been restricted in many countries.

In ruminants, the inclusion of antibiotics, particularly ionophores, significantly influences rumen metabolism. Improvements in feed conversion efficiency and growth performance are associated with alterations in the production and proportions of volatile fatty acids (VFAs) in the rumen. Specifically, ionophores increase the molar proportion and production rate of propionate while reducing acetate and butyrate levels, thereby enhancing energy efficiency¹. Studies have demonstrated that monensin supplementation increases total VFA production per unit of dry matter intake, indicating improved fermentation efficiency. Additionally, ionophores contribute to a reduction in methane production in both cattle and sheep, reflecting a shift in rumen microbial activity². These changes collectively improve nutrient utilization and productivity, highlighting the role of antibiotics as potent modifiers of rumen fermentation, although their use must be carefully regulated.

2.2 Probiotics

Probiotics are defined as live microbial feed supplements that beneficially affect the host animal by improving the balance of intestinal microflora. These beneficial microorganisms enhance digestive efficiency by producing enzymes that complement the host's digestive processes and by forming a protective barrier against invading pathogens. Supplementation of diets with compound probiotics has been reported to alter rumen fermentation patterns and promote rumen development, thereby improving overall animal performance³. The desirable effects of probiotic organisms are exerted through multiple mechanisms, including adherence to the intestinal mucosa to prevent colonization by pathogenic microbes such as *E. coli*, neutralization of enterotoxins responsible for fluid loss, bactericidal activity as exhibited by *Lactobacilli*, inhibition of harmful amine synthesis by coliform bacteria, and enhancement of the host's immune response.

In monogastric animals, commonly used probiotic strains include *Lactobacilli*, *Bacillus subtilis*, and *Streptococci*, whereas in ruminants, yeast cultures, particularly *Saccharomyces cerevisiae*, have demonstrated considerable efficacy. These may be administered as live cells or as dead cells along with their culture extracts. Metabolites derived from yeast, including B- vitamins, amino acids, and peptides, stimulate the growth of beneficial rumen bacteria such as *Megasphaera elsdenii*, which plays a key role in utilizing lactic acid produced during rapid fermentation of starch-rich diets. Additionally, live yeast competes with lactic acid-producing bacteria by fermenting sugars, thereby stabilizing

rumen pH and reducing the risk of acidosis. Yeast cultures also help maintain anaerobic conditions in the rumen by scavenging oxygen, which favours the growth of cellulolytic bacteria. Collectively, these effects lead to increased forage intake, improved nutrient utilization, enhanced live weight gain, and higher milk yield and milk fat content, highlighting the importance of probiotics in animal nutrition.

2.3 Prebiotics

Prebiotics are defined as non-nutritive compounds that beneficially influence the host by selectively modifying the composition and activity of the gastrointestinal microflora, thereby promoting a healthier intestinal environment. These substances undergo selective fermentation in the gut, leading to the proliferation of beneficial bacteria and improved gut health⁴. Prebiotic compounds include certain proteins, peptides, fats, and a wide range of oligo- and polysaccharides such as cellooligosaccharides, inulin, and lactulose. Oligosaccharides occur naturally in several feed ingredients, including alpha-galactooligosaccharides (GOS) in soybean meal, rapeseed meal, and legumes; fructo-oligosaccharides (FOS) in cereals; trans- galactooligosaccharides (TOS) in milk products; and mannan-oligosaccharides (MOS) in yeast cell walls. In addition to natural sources, these compounds are also produced commercially for inclusion in animal diets.

The beneficial effects of prebiotics are largely attributed to their interaction with pathogenic microorganisms in the gut. Pathogenic bacteria possess surface molecules known as lectins, which recognize and bind to specific carbohydrate structures present on the intestinal mucosa, facilitating their attachment and colonization. This lectin-carbohydrate interaction is highly specific for different microbial species. For instance, pathogens such as *Salmonella* and *Escherichia coli* exhibit mannose-specific lectins that bind to mannose residues on the gut epithelium. However, when similar oligosaccharides are included in the diet, these pathogens preferentially bind to the free carbohydrates rather than to the intestinal wall. As a result, they are prevented from adhering to the gut lining and are subsequently excreted without producing harmful toxins. Thus, prebiotics play a crucial role in maintaining gut health by inhibiting pathogen colonization and promoting beneficial microbial populations.

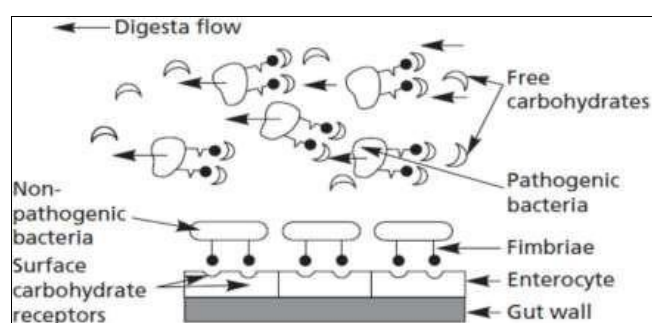


Fig 1: Mechanism of action of prebiotics

2.4 Arsenicals

Arsenicals, including compounds such as arsanilic acid, sodium arsanilate, and 3-nitro- hydroxyphenyl arsenic acid, have been used as feed additives to inhibit the growth of pathogenic microorganisms and to support recovery in animals under stress or disease conditions. These compounds exert their effects by controlling harmful microbial populations, thereby improving overall animal health and performance. The retention of arsenic residues in animal

tissues is generally low; however, to ensure food safety, it is recommended that arsenicals be withdrawn from the diet at least five days prior to slaughter. Typically, these compounds are included in feed at a level of 50–70 g per tonne. Despite their historical use, concerns regarding toxicity and residues have led to increased scrutiny and regulatory restrictions in many countries.

2.5 Buffering Compounds

Buffers are mixtures of weak acids and their conjugate bases that function primarily as neutralizing or alkalinizing agents. When present in aqueous solutions, they resist changes in pH upon the addition of acids or bases, thereby maintaining a stable environment. In ruminant nutrition, buffers play a crucial role in modifying ruminal fermentation by stabilizing rumen pH and preventing excessive acidification, particularly under high-concentrate feeding conditions.

The inclusion of buffering agents in the diet helps maintain optimal ruminal pH, enhances the fractional outflow rate of rumen contents through the reticulo-omasal orifice, and increases ruminal fluid dilution rate. This increase in dilution rate is attributed to higher osmolarity, which promotes greater water intake and influx across the ruminal wall. Commonly used buffers in dairy cattle include sodium bicarbonate (NaHCO_3) and magnesium oxide (MgO), which are effective in counteracting the depression in milk fat synthesis associated with low ruminal pH and an altered acetate-to-propionate ratio in diets low in roughage and high in concentrates. Sodium bicarbonate is typically supplemented at 0.6 to 0.8% of the total mixed ration or 1.2 to 1.6% of the concentrate mixture, while magnesium oxide is added at 0.2 to 0.4% of the total mixed diet or 0.4 to 0.6% of the concentrate mixture. These buffering agents thus contribute significantly to maintaining rumen health and improving productive performance in dairy animals.

2.6 Antioxidant

Antioxidants are chemical compounds that prevent the oxidation of substances by scavenging oxygen, thereby protecting feed components from oxidative deterioration. Feed ingredients rich in fats and oils, such as vegetable oils, lard, fish meal, and poultry by-product meal, are particularly susceptible to oxidative rancidity. This oxidation leads to the development of off-flavours, which can reduce voluntary feed intake and negatively affect the bioavailability of essential nutrients, especially amino acids and fat-soluble vitamins such as vitamins A and E.

Antioxidants used in animal nutrition are broadly classified into synthetic and natural types. Common synthetic antioxidants include butylated hydroxyl anisole (BHA), ethoxyquin, and butylated hydroxyl toluene (BHT), while natural antioxidants include vitamins such as vitamin E and vitamin C. Among dietary antioxidants, vitamin E, vitamin C, vitamin B complex, and beta-carotene are the most extensively studied. Natural sources of these antioxidants include fruits and vegetables, which are rich in vitamin C and carotenoids, as well as whole grains and high-quality green forages, which are major sources of vitamin E. In practical feeding, antioxidants are typically added to feed ingredients and vitamin premixes at levels ranging from 125 to 200 g per tonne of feed. Synthetic antioxidants are generally preferred due to their cost-effectiveness and longer shelf life, making them highly suitable for maintaining feed quality during storage.

2.7 Enzymes

Enzymes are important feed additives that enhance nutrient utilization and improve overall animal performance. Fibrolytic enzymes such as cellulase, phytase, xylanase, and β -glucanase play a significant role in breaking down complex feed components, thereby increasing the efficiency of nutrient digestion and reducing the anti-nutritional effects of certain feed ingredients, particularly in non-ruminants. In ruminant animals, although rumen microorganisms naturally produce adequate quantities of these enzymes, supplementation with exogenous enzymes can provide additional benefits. These externally supplied polysaccharide-degrading enzymes are stable in the rumen environment and may also pass to the lower gastrointestinal tract, further contributing to improved nutrient utilization.

The inclusion of exogenous fibrolytic enzymes, such as cellulase, hemicellulase, and β -glucanase, in concentrate supplements has been shown to enhance feed intake, digestibility, and rumen function. Studies have demonstrated that enzyme supplementation can positively influence the rumen environment, leading to improved fermentation and nutrient availability⁶. Overall, the use of enzymes as feed additives represents an effective strategy to optimize feed efficiency and support better growth and productivity in livestock.

2.8 Hormones

Hormones are biologically active substances produced by endocrine glands that act on specific target organs to elicit desired physiological responses. In animal nutrition, both naturally occurring hormones and their synthetic analogues are utilized as feed additives to promote growth and enhance productivity by modulating metabolic processes. These compounds are employed to bring about desirable changes in the rate and efficiency of metabolism, thereby improving growth performance, milk yield, or egg production.

Hormones used in animal production are broadly classified into anabolic and catabolic types. Anabolic hormones, such as growth hormone and thyroxine, primarily stimulate tissue synthesis and are used to enhance overall productivity. For instance, bovine somatotropin is widely recognized for its role in increasing milk production in dairy animals. On the other hand, catabolic hormones, including estrogen and glucocorticoids, influence nutrient partitioning by promoting muscle and bone development at the expense of fat deposition. Despite their effectiveness, the use of hormonal feed additives has raised significant public concerns due to the potential presence of residues in animal products, which may pose risks to human health. Consequently, the use of such hormonal preparations has been restricted or banned in several countries, emphasizing the need for safer alternatives in livestock production systems.

2.9 Adsorbent

Adsorbents are feed additives that are not absorbed from the gastrointestinal tract but possess the ability to bind physically with toxic substances, thereby preventing their absorption into the animal's system. These compounds play a crucial role in protecting livestock from the harmful effects of dietary toxins, particularly mycotoxins such as aflatoxins commonly present in contaminated feed. The inclusion of adsorbents in animal diets helps to reduce toxin bioavailability and minimize their adverse effects on health and productivity.

Commonly used adsorbents include activated charcoal and various silicate-based compounds, which are widely applied

in livestock feeding. Activated charcoal is typically administered at a dosage of 20–120 mg per kg body weight in domestic animals. In addition, substances such as aluminosilicates, bentonite, silica, and zeolites have been found to be effective in binding mycotoxins and reducing their toxicity. These adsorbents thus serve as an important preventive strategy in animal nutrition, ensuring feed safety and supporting optimal animal performance.

2.10 Organic Acids

Organic acids are important feed additives that act as potent rumen modifiers, influencing fermentation patterns and improving nutrient utilization in ruminant animals. Among these, malic acid and fumaric acid are particularly effective in regulating rumen metabolism. Malate plays a key role in stimulating the utilization of lactic acid by rumen bacteria such as *Selenomonas ruminantium*, thereby helping to prevent the accumulation of lactic acid and reducing the risk of ruminal acidosis. Studies have indicated that malate is more efficient in promoting lactate utilization compared to fumarate or aspartate.

Forages rich in malate, such as lucerne and Bermuda grass, can be strategically incorporated into ruminant diets to support rumen manipulation and enhance fermentation efficiency. Fumarate has also been found to be beneficial, particularly in diets rich in fibre, as it supports improved rumen function and digestion. In addition to malate and fumarate, other organic acids such as citrate and formic acid are also utilized in animal feeding for their beneficial effects on rumen environment and microbial activity. Overall, the inclusion of organic acids contributes to improved rumen health, better feed efficiency, and enhanced animal productivity.

2.11 Flavouring Agents & Pigments

Flavouring agents are commonly used as feed additives to enhance the palatability of animal feeds, particularly in diets containing ingredients such as fish meal and certain vegetable protein sources that may have less desirable taste or odour. These additives are especially important in the diets of flavour-sensitive animals, such as pets, where feed acceptance is critical for maintaining adequate intake and performance. By improving the sensory characteristics of feed, flavouring agents help ensure consistent consumption and better nutrient utilization.

In addition to flavour enhancers, pigmentation compounds are incorporated into animal diets to meet consumer preferences for the appearance of animal products. Xanthophylls, naturally present in ingredients such as yellow maize and lucerne meal, are widely used to impart a desirable deep yellow colouration to body tissues and egg yolk. These pigments play an important role in enhancing the market value and consumer acceptability of products such as poultry meat and eggs, thereby contributing indirectly to the profitability of livestock production systems.

3. Conclusion

Feed additives play a crucial role in enhancing feed efficiency, animal health, and overall productivity by modulating rumen fermentation and improving nutrient utilization. Various additives, such as antibiotics, probiotics, prebiotics, enzymes, buffers, and organic acids, act through different mechanisms to optimize digestive processes and stabilize the rumen environment. While traditional additives like antibiotics and hormones have shown significant benefits,

their use is increasingly restricted due to concerns over antimicrobial resistance and residues in animal products. Consequently, there is a growing emphasis on safer and sustainable alternatives such as probiotics, prebiotics, and enzyme-based additives. Additionally, compounds like antioxidants, adsorbents, and buffers contribute to feed quality and animal well-being. Overall, the judicious use of feed additives is essential for achieving efficient, sustainable, and safe livestock production systems.

Conflict of Interest

Not available

Financial Support

Not available

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