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Importance of Nutrition in facilitating ruminant physiological processes and productive performance

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I. Abstract

The manner in which we control ruminant nutrition directly affects the productivity and general well-being of these animals. Alongside that of production, reproduction, and the yield of milk and/or meat, an optimum nutrition has beneficial impacts on crucial physiological processes required for general well-being. The objective of this systematic review is to compile recent studies in this area on the benefits that could be associated with the diet of ruminants (sheep, goats, cattle etc.) regarding their physiological well-being and productivity. This document really emphasizes the value of critical dietary nutrients like energy sources, proteins, minerals, vitamins and feed additives. The role of feeding methods, such as supplements, fodder quality and frequency of feeding is also discussed. In summary all of the above leads to higher production levels and better adaptation to disease resistance. Recent advances in nutritional engineering, such as probiotics, prebiotics, and phytogenic substances, which hold considerable promise for the enhancement of physiological responses, are also presented in the article. It is also highlighted in the paper that specific dietary plans that respond to individual animals' condition based on their age, physiological status, and production goal are of significant value in managing ruminants more effectively. There is considerable progress to be made, nevertheless, concerning the application of scientific discoveries into practice, especially in regions where lack of resources exist. All of the above leads to higher production and adaptation to disease resistance. It is also highlighted in the paper that the latest nutritional engineering technologies such as probiotics, prebiotics and phytogenic substances hold immense potential for enhancing physiological responses. The review also reiterates the significance of the individual feed regime in effective ruminant management (age, condition and production of animal). However despite significant advances, it is still not feasible to implement all experimental results on-farm (especially in areas lacking funding) but a lot of ground was covered. In conclusion this study highlights the importance of sound nutrition in improving performance and physiology of the ruminant. In turn, welfare, production and economics of the animal is greatly improved. Ruminants (which supply the world with meat, milk and fibers) form a vital part of the world's food system but their nutrition greatly influences physiology and productivity. It was the objective of this systematic study to assess the improvement in the performance and physiology of the ruminant via its nutrition.

Key word *: Ruminant, Performance, Minerals, Vitamin , Probiotics ,Lipid*

II. Introduction

The ruminants, cattle, sheep and goats are of fundamental importance to agriculture throughout the world, producing a range of commodities such as meat, milk, wool and leather. They are of importance to our diet and as sources of nutrients and income to rural people due to their unique ability to convert indigestible plant material into nutritional substances. These animals' physiological functions, their performance (growth rate and reproduction) and their general state of health are greatly influenced by nutrition. In particular their digestive capabilities, metabolic functions and the level of the immune response of these animals are all influenced by adequate nutrition with special emphasis placed on protein. Thus they produce more efficiently and are more resistant to disease. In recent years, people have also been considering the diet of ruminants and how it contributes to productivity and welfare. Previously it may have been conjecture but the results of scientific studies indicate that their diet contributes to their overall vitality and the efficient functioning of the animal. Studies in this field are increasingly pointing towards feeding strategies which contribute to long-term resilience on a farm. Ruminants have an interesting physiology. It takes four compartments (rumen, reticulum, omasum and abomasum) for it to be able to derive useful energy from tough plants (Lei *etal* .,2018). Their remarkable adaptive ability allows them to produce useful goods from such low-quality food sources and explains their importance in arid regions where few other animals can thrive. In terms of the importance in biological processes, food sources and nutrition are essential to biological processes. It is important for nutritionist to understand the diet for ruminants in order to improve production and manage the metabolic processes. Food has a close association with activity of ruminants, which their gastrointestinal tract have been designed specifically to accommodate fermentative (anaerobic microbial) process occurring primarily in the rumen, that allows breakdown of structural carbohydrates into gases, microbial protein and VFAs. Unstable fatty acids (VFAs) of acetate, propionate and butyrate are the primary energy supply for these animals. Rumen microbial flora are also essential to synthesis of essential amino acids and vitamin to enable myriad of physiological. Nutrition can affect many different physiological functions in ruminants such as, immunity, growth, lactation, reproduction and control of metabolism. A sufficient supply of energy, protein, minerals and vitamins to facilitate optimal microbial fermentation, development and hormonal control are all needed. Malfunction of the metabolism, loss of feed efficiency and suppression of immune responses will occur when there is a deficiency in some nutrients. An understanding of how different nutrients affect physiological response would therefore have to be established before sound nutritional protocols could be put in place. It will be our aim in this review to fully explore the role of nutrition on ruminant physiology and performance. We would aim, firstly, to illuminate how the physiological systems and nutrition interact in the ruminant, and second The impact of the various feeding strategies will be evaluated for their effects on growth, reproduction, lactation, and general well-being. We want to investigate how technological advancement and feed additives could enhance nutrition. The prospects and challenges in sustainable feeding of ruminants will be addressed at the end.

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Ruminant Digestion and Nutritional Needs

The ruminant digestive system is divided into four compartments namely, reticulum, rumen, omasum and abomasum. Most of fermentation is done in the rumen (Tharwat *etal*., 2012 **).** The rumen is a fermentation vat where microorganisms living within the rumen use enzymes to ferment food consumed by ruminants (Aschenbach *etal.*, 2011). Microbial populations in the rumen can be affected by several parameters: temperature, pH, buffering capacity, osmotic pressure and redox potential. These factors are influenced by the surrounding environmental conditions. The digestion process in ruminants is a complex series of events that happen in various parts of the gastrointestinal tract. This process involves the fermentation of dietary components by microbes in the reticulorumen, followed by acid hydrolysis and enzyme degradation in the abomasum and small intestine, and finally, secondary fermentation in the cecum and large intestine. The location where digestion takes place plays a crucial role in determining the types of nutrients that are absorbed and how much is lost during the process. Therefore, measuring the site of digestion is essential for understanding how ruminants utilize nutrients (Merchen *etal*., 1997). Ruminants' digestive systems is unusual and let them to ferment fibrous meals right in their rumen. This fermentation process is one of nature's most effective ways to turn complex organic materials into nutrients that can be used. In ruminants, the microbial fermentation happening in the rumen transforms plant structural carbohydrates into volatile fatty acids, which serve as a key source of metabolic energy for the animal. Other fermentation processes may be described with hind-gut fermenters such as horses, rabbits and many other animals. This enhancement of digestive efficiency and nutrient conversion depends upon large intestinal and caecal micro-flora. These microbial ecosystems are highly intricate, unstable and are the outcome of interaction of microflora, host biology and feed characteristics. Fermentation has a vital role in feed manufacturing and utilization not just within the digestive tract but elsewhere too . Technologies such as the production of silage rely on microbial fermentation to stabilize plant biomass, improve feed quality, and reduce nutrient losses.

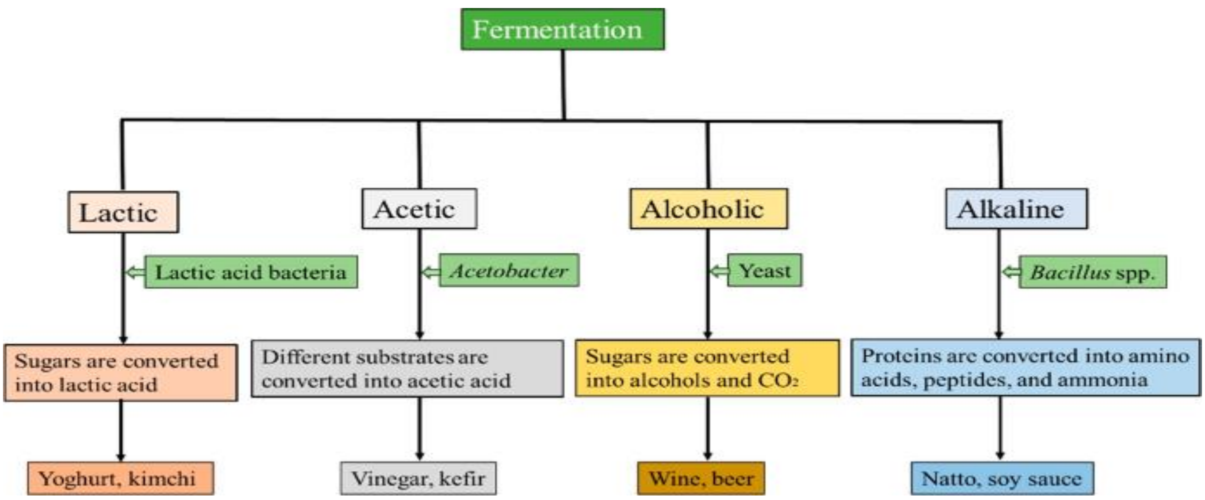

Figure 1. common types of fermentation, associated microorganisms, and ultimate products (Sawant *etal*.,2025).

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In recent years, fermentation-based methods have expanded to include microbial inoculants, fermented feed components, and innovative feed additives meant to enhance animal productivity and health. These processes represent how fermentation methods can possibly increase the resilience and efficiency of livestock production systems (Gierus,2026). Rumens operate as a diverse ecosystem where fiber, fungi, bacteria and protozoa break down the nutrient intake. VFAs and microbial biomass are the chief fermentation end products which is utilized by the host ruminant. Ruminants derive their benefits of eating high-fiber, low-protein diets by the host's symbiosis and there is the right environment for bacteria in their rumens to produce the enzymes to breakdown the nutrients. Ruminants are capable of converting low-value fiber material into human products beneficial, for instance meat, milk and fibers (Castillo *etal.*, 2014). The capability of ruminal microbes to produce the required enzymes to undertake the fermentation, makes the use of energy content in forages effective (Burns,2008). However, not all the ruminal fermentation process is effective as methane is produced as the fermentation end-product(Chen *etal.*, 2022).

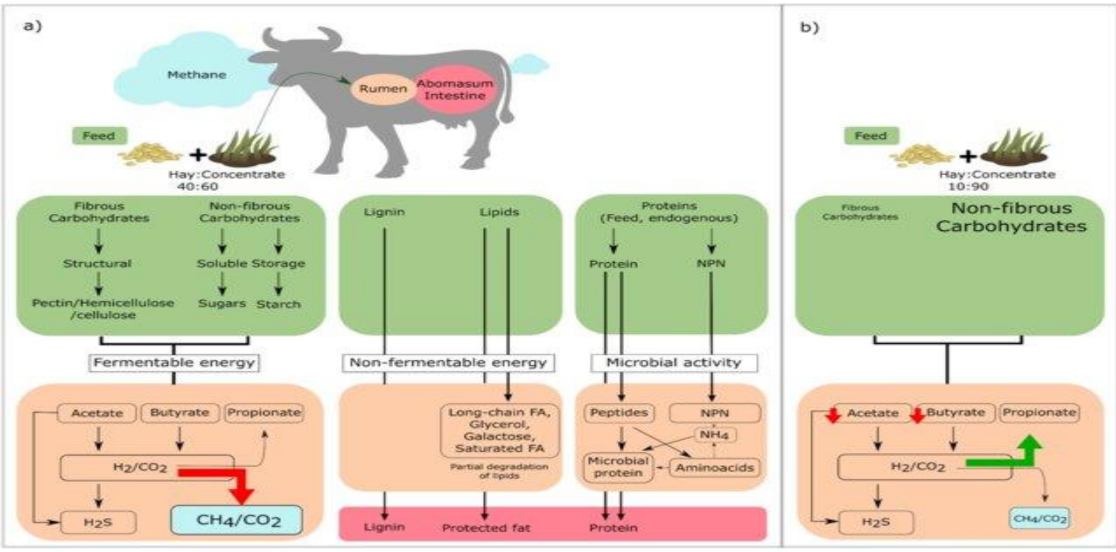

Figure 2. The ruminant fermentation process (McCauley *etal.*, 2020)

Dietary composition's effects on ruminant physiological function and performance

Ruminant performance and health are significantly influenced by their diet. **Water, minerals, vitamins, proteins, lipids,** and **Carbohydrates** make up the majority of their diet. To maximize ruminant nutrition, it is essential to comprehend the roles that each of these elements plays and how they interact.

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III. Carbohydrates :

Within ruminant diet the largest category is carbohydrates, this category can be further broken down into two classifications of carbohydrates- the fiber carbohydrates and non-fiber carbohydrates (NFC). Generally speaking 60-70% of the ruminant diet consists of other substances, starches, sucrose, pectins and others; this is important for supplying the rumen microbes and keeping the ruminants gut healthy (Rugota,2021). Carbohydrates are important because they supply the energy the animal needs for growth, reproduction, milk production and generally high health (Wang *etal*., 2012). Ruminants obtain their carbohydrate from concentrates, cereals and forages. The animal has a curious four-compartment stomach system and within this it has the rumen in which occurs microbial fermentation. In this component the microbes ferment carbohydrate materials such as cellulose and hemicellulose to produce volatile fatty acids (VFAs), butyrates, acetates and propionates (Lee,2023) which are absorbed and used as energy; propionate one of the volatile fatty acids (VFA) is an important precursor for gluconeogenesis within the liver and this is required to maintain adequate blood glucose levels (Wang *etal*.,2012). Besides producing beneficial bacteria that help create and maintain a good environment in the rumen, fermentation also helps with digestion and prevents problems (Ferrira *etal*., 2020). Ruminants can effectively obtain energy from fibrous plant materials that are difficult for monogastric animals to digest thanks to this fermentation.

When it comes to ruminant performance, adequate carbohydrate intake, it enhances growth by providing the energy necessary for muscle development and weight gain (Broderick *etal*., 2002) and improves milk production by supplying the energy needed for lactation. Supporting Reproductive Efficiency by meeting the energy needs for conception and the healthy growth of the fetus. Maintaining Health, metabolic issues like ketosis and acidosis that can crop up from unbalanced diets. Making sure there's enough carbohydrate intake is key to providing the pregnant dam with the energy needs, which in turn supports optimal fetal growth and development. Rumen microbes work their magic by fermenting carbohydrates into volatile fatty acids (VFAs) like acetate, propionate, and butyrate, which are vital energy sources. Propionate, in particular, plays a crucial role as a precursor for glucose production in the liver, Propionate, a significant precursor of liver gluconeogenesis, can regulate the key genes involved in hepatic gluconeogenesis expression (Pang *etal*., 2023) fueling fetal growth, when energy levels are improved, it enhances the transfer of nutrients to the fetus through the placenta. Additionally, the stages of fetal growth and the timing of parturition can both be impacted by balanced carbohydrate levels. Therefore, it is crucial to consume the proper kinds and quantities of carbs. High-starch diets can increase energy levels, but they must be properly controlled to prevent acidosis. In ruminant nutrition, fiber is crucial. Fiber is necessary to keep animals healthy and to maintain proper rumen physiology and function (Aghsaghali *etal*., 2011). In terms of nutrition, fiber's physical and chemical characteristics are connected to both the enzymatic breakdown linked to fermentation and the mechanical digestive processes of chewing and passing (Banakar *etal*., 2018). On the other hand, high-fiber diets can reduce the intake of energy but are beneficial for rumen. Thus, the productivity and performance of ruminants can be substantially elevated when the ration is formulated to enhance the fermentation of carbohydrates. Achieving optimal carbohydrates is essential for ruminants because carbohydrates are critical in providing the necessary energy for growth, reproduction, and milk production. The importance of carbohydrates in ruminants stems from the fact that it is their major source of energy, via fermentation in the rumen, which helps to sustain various physiological processes of the ruminants.

Proteins are indispensable component of the diet of ruminants and important in affecting ruminant performance and functions (Saro *etal*., 2020; Ali *etal*.,2009; Agwaan,2023; Alkhashab *etal*., 2023). Protein in the diet of the ruminants are fermented in the rumen and resulted in microbial protein that serves as a source of amino acids. Quality and supply of protein influence different aspect of health status and performance of the ruminants. An

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optimal supply of dietary protein to improve growth is essential and increasing dietary protein level increase growth rate and improves the feed conversion ratio of lambs (Imaizumi *etal.,* 2010).

Additionally, milk production benefits from proper protein intake (Eastridge,2006; Aguilar *etal* ., 2012; Salo,2018; Funston,2014) Protein supplementation for dairy cows is a common practice aimed at boosting reproductive activity (Funston,2014). However, it's important to note that too much protein can negatively impact reproduction .However, inadequate protein intake might result in reduced milk production and less rapid growth rates. Excess protein can also cause inefficient nitrogen use and more waste. Proteins are essential because they provide the amino acids needed for muscle growth and repair, which helps with physical development and maintaining body tissues. Additionally, proteins play a crucial role in creating enzymes that speed up chemical reactions in the body, including digestion and energy production(Wanga *etal*., 2017). For instance, amylase is an enzyme that plays a crucial role in breaking down starches into sugars. Additionally, some hormones are proteins, such as insulin, which helps regulate blood sugar levels. The protein structure of hormones enables them to attach to specific receptors and initiate various responses. Necessary for metabolic processes, immunological responses, and general physiological balance, antibodies also proteins help to identify and neutralize foreign intruders including viruses and bacteria. Other immune molecules, such as cytokines, help immune cells to connect. Maintaining the proper levels of protein is essential for promoting strong microbial ecosystems in the rumen, which then aids with efficient fermentation and nutrient absorption. Nitrogen retention and excretion is heavily dependent upon the form and amount of dietary protein. By appropriately balancing both the degradable and non-degradable fraction of dietary protein, we can best optimize nitrogen utilization.

Fat: Ruminants require fats as they play a role in the functioning of these animals' physiology and productivity in several major ways. Fat is an integral part of ruminant nutrition as it is a primary energy source (Bauman *etal.,* 2003). At the same value per unit they contain approximately 2.25 more energy than carbohydrates do. Adding fats into ruminant diets provides these animals with an increase in energy content which is beneficial for the animal to grow, reproduce and produce milk. An increase in the amount of fat added into the diet, and an increase in the fatty acid composition, and an increase in fat content (in particular unsaturated fats) could provide positive results in the production of milk and could potentially increase the nutritive quality of milk (Schroeder *etal.,* 2004).

Lactating cows' production, fertility, and energy levels can all be significantly increased by lipid supplementation (Palmquist *etal*., 1980)When moderate amounts of lipids are added, they may actually suppress some microbial populations and affect rumen fermentation patterns. Indeed, the supplementation of the diet with 0.1% esterified fatty acids of glycerol has been shown to stimulate the proportion of fiber degrading microorganisms (Yang *etal*., 2025) and although this could reduce fiber digestibility, it also reduced methane output which would be beneficial for the environment. Lipids play an important role in immunological response, hormone synthesis, and in the stability of cell membranes and thus adequate intake is necessary for health. However, excessive lipid supplementation may disrupt the microbial activity in the rumen, cause lipid toxicity, or impede the digestion of fiber. Therefore, regulating lipid levels is important.

Oilseeds like soybean and sunflower, fats, and particular bypass fats created to evade rumen breakdown and give energy straight to the animal are typical sources of lipids. Particularly given how they impact rumen fermentation, lipids are essential dietary components that can improve ruminant performance and sustain general health.

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All metabolic processes occurring in ruminants require minerals and vitamins to function normally. Both deficient dietary levels of minerals and vitamins, or excessive amounts, can cause a large financial loss of livestock productivity(Spears *etal.*, 2014),**Minerals** and **vitamins** are key nutrients that are essential for keeping ruminants healthy and functioning well. Getting the right amounts and balance of these nutrients is crucial for their growth, reproduction, milk production, and immune health. **Macrominerals** like **calcium (Ca), phosphorus (P), magnesium (Mg), sodium (Na), and potassium (K)** are needed in larger amounts. They play a vital role in bone growth, muscle function, nerve signaling, and maintaining acid-base balance. On the other hand, **microminerals** or trace minerals such as **zinc (Zn), copper (Cu), manganese (Mn), selenium (Se), and iodine (I)** are not only vital for enzyme functioning but also play a role in antioxidant defense and several other metabolic processes. Besides minerals, vitamins are also an essential requirement for ruminants to maintain their health. Examples of **fat-soluble vitamins** are **A D E, and K** while **water-soluble** ones include the **B-complex group and vitamin C. Vitamin A** has multiple functions including maintaining good vision, a healthy immune system, and growth of cells. On the other hand, vitamin D is very important for enhancing the body's capability to take in calcium and phosphorus that are highly needed for the development of strong bones. Vitamin E and selenium together perform the function of antioxidants by protecting cells from damage caused by oxidation. They also play a vital role in maintaining energy metabolism and the nervous system. If animals are lactating, they will require a higher intake of vitamins because these vitamins will not only help them meet their increased metabolic needs but also be involved in the production of milk(Ashwin *etal.*, 2018). When we deprive our bodies of vitamins, it can result in various problems such as bad reproductive health, a weak immune system, and even metabolic disorders. On the flip side, ensuring that animals have the right balance of minerals and vitamins can significantly boost their feed efficiency, growth rates, reproductive success, milk production, and overall resistance to diseases. However, if there's too little or too much of these nutrients, it can disrupt bodily functions, resulting in lower productivity and health problems for ruminants.

A variety of dietary mineral elements are needed by beef cattle for normal maintenance, developmental and reproductive growth. Minerals that are required in relatively large quantities are known as major/mineral macro; whereas, those that are required in small quantities are classified as micro/minor/trace minerals. However, the terms micro/minor/trace have nothing to do with a mineral's metabolic importance when it is in the diet. In other words, a trace mineral can be equally important to an animal's health and performance as a major mineral. The list of **major minerals** includes **calcium, phosphorus, magnesium, potassium, sodium, chlorine and sulphur. Calcium** assists with the formation/maintenance of bone/teeth and helps transmit impulses in neurons and contract muscle tissue. Calcium plays a vital role in developing & maintaining normal bones. Therefore, if there is inadequate calcium available during the developing stage, young animals will develop skeletal deformities due to not having enough calcium to support their skeletal growth. The critical period(s) for ensuring that diets provide sufficient amounts of calcium are during gestation (i.e., developing fetuses) and lactation (i.e., making sure lactating cows do not have to mobilize too much calcium from their bones). The milk fever (parturient paresis or hypocalcemia) that occurs when a cow gives birth is due to too much calcium being taken out of the bones (skeletal system) of the cow during milk production; the cow will have symptoms of muscle tremors, stiffness, weakness or loss of consciousness. Hypocalcemia is a slow developing, non-febrile neuromuscular dysfunction seen most often in high producing dairy cows, but it can also be found in small ruminants. Hypocalcemia will result in flaccid paralysis, decreased circulation, and decreased sensation (Smith and Sherman,2009; Constable *etal.,* 2017). Hypocalcemia occurs because of the increased movement of ionized calcium (Ca^{++}) from the blood plasma, with no corresponding intestinal absorption or bone resorption of calcium being increased (Kimberling,1988). When producing bone, phosphorus is needed along with calcium. DNA is made of phosphorus and carries the genetic information about chromosomes. **Phosphorus** is involved in the body's chemical reactions that use energy. Compounds such as ATP and creatine phosphate are the major forms of storage for the body's readily available energy. Phosphorus Deficiency is responsible for reducing an animal's ability to grow, reproduce, and produce milk. **Magnesium** is responsible for activating many of the

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metabolic enzymes that are involved in everything from breaking down glucose into the energy needed to replicate DNA to allow for the cell to divide. The most typical ailment related to magnesium deficiency is grass tetany. **Potassium** is found throughout the body of mammals, primarily because it is needed in large amounts by most of the body's organ systems to function normally. Therefore, when there is a deficiency of potassium, the animal will exhibit non-specific symptoms (i.e., loss of appetite), which will be followed by weight loss and decreased performance as well as stiff and sore front leg joints. **Sodium and chlorine** are often referred to as sodium chloride or "salt. Sodium and chlorine both play vital roles in regulating total body fluids volume, pH and osmolarity; sodium also contributes to muscle and nerve activity; chlorine is a necessary component of hydrochloric acid made in the abomasum as well as carbon dioxide transport. Chlorine and sodium chloride are also two important minerals that are required for animal health. The lack of sodium or chlorine can result in decreased feed intake, dehydration, and an electrolyte imbalance, while their excesses can result in either salt poisoning or lack of water. **Sulfur** is part of protein, some vitamins (thiamin, biotin), enzymes, etc. The recommended amount of sulfur (S) is one of the basic building elements in the diet (dry matter basis) for the growth and finishing of cattle is 0.15%. Sulfur levels in the diet over 0.4% of the dry matter (DM) are potentially toxic, sulfur represents an essential element for rumen microbes and is closely related to nitrogen metabolism, Sulfur is an important constituent of amino acids, enzymes, and vitamins in humans and animals. Sulfur is a component of various organic nutrients required by ruminants , It is crucial for producing certain enzymes, vitamins, hormones, and amino acids in the rumen, including cystine, methionine, and cystine, In ruminants, sulfur supplementation is essential for overall health, growth and production, amino acid balance, and wool quality, Despite this, excessive sulfur digestion may cause a toxic effect on animals and adversely affect animals' performance and health, even causing serious diseases such as polioencephalomalacia (PEM). High sulfur levels in diets can significantly reduce animal performance, decrease milk production and sometimes even result in death(Malyugina,2023). Excess sulfur can disrupt the metabolism of other trace minerals such as selenium, copper, molybdenum and thiamin. Symptoms of sulfur deficiency include reduced feed intake, poor body condition, dull coat and hair loss. High to very high sulfur levels in the diet can result in rumen animals developing polio encephalomalacia. Polio encephalomalacia is characterized by wandering aimlessly, being blind, muscle tremors and convulsing. Maintaining an appropriate level of vitamins and minerals is important to achieve good health and performance in ruminants. Deficient or excessive amounts of mineral and vitamin nutrients can produce serious health-related problems, which highlight the importance of appropriate dietary requirements and supplementation as needed for optimal health and performance in ruminants.

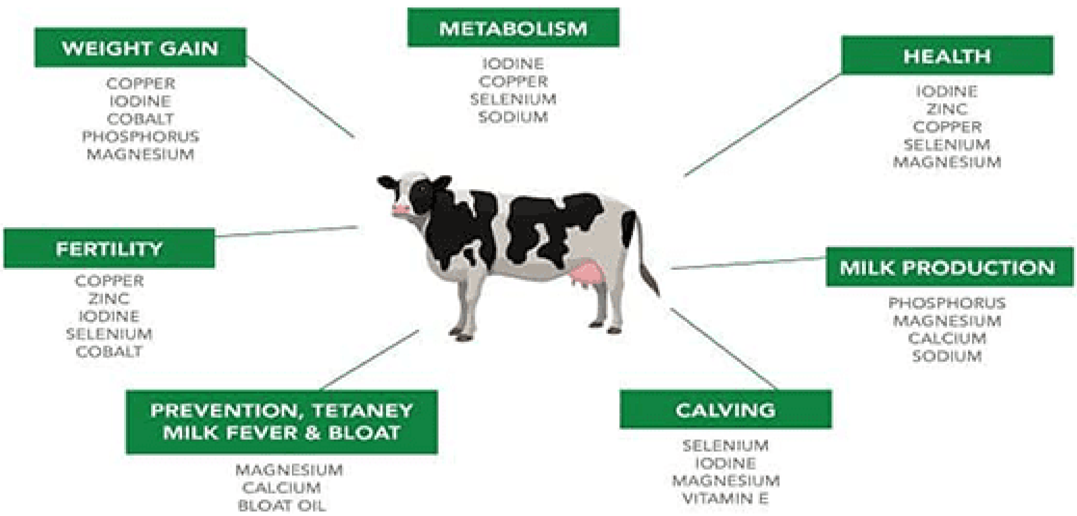

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Figure 3.The Importance of Minerals in a Dairy Cow

Water is one of the most important nutrients and is consumed more than any other nutrient by livestock. Water is also the most abundant molecule found in all living cells(NRC,2007) Water is an important component of nearly every physiological function of the animal. (Aganga *etal*., 1986) reviewed the importance of water in ruminant livestock production and more recently (Araújo *etal*., 2010) Water is absolutely essential for the health, performance, and overall physiological functions of ruminants (Wilson,1981). water is key to staying hydrated, aiding digestion, and supporting various metabolic processes. Let's take a closer look at how water impacts ruminant performance and their physiological functions. It plays a crucial role in the fermentation process within the rumen, where it helps dissolve nutrients and boosts microbial activity. Staying properly hydrated is key for good digestion and making sure your body absorbs nutrients effectively. Water plays a crucial role in regulating your body temperature through processes like sweating and breathing. Water is the main factor for animal nutrition and any changes in its availability may lead to direct alteration in behavior of animals(Kumar *etal*., 2015; De *etal*., 2015b) In arid environments, ranging animals are usually faced with water scarcity due to long distance walks in search for water. Thus, these animals have developed different behavioral and physiological adaptation mechanisms which enable them to tolerate dehydration (De *etal.,* 2015b ; Hamadeh *etal*.,2006;Ghassemi *etal*., 2015). Water deprivation is one of the main factors which affect ruminants' behavior due to water availability. When you drink enough water, it helps prevent heat stress, which can hurt your appetite and overall productivity. Plus, water acts as a solvent for many biochemical reactions and is essential for moving nutrients, hormones, and waste around in your body. For dairy cows, the amount of water they drink has a direct impact on both the quantity and quality of the milk they produce. Insufficient water can really take a toll on milk production and even lead to some serious udder health issues. To create the best possible metabolic and physiological conditions for animals, sufficient hydration is essential for optimum growth rates and reproductive functions. When animals drink sufficient amounts of water, their immune system is supported and the chance of developing health issues due to dehydration like kidney and constipation problems is reduced. The health, productivity and physiological functioning of ruminants depend significantly upon availability and quality of water. Providing clean, fresh water for them all the time will improve their performance and overall well-being. Surprisingly, the physiological phase of a creature influences his or her water intake needs.

For instance, in sheep, the water requirement jumps by 126% from the first to the fifth month of gestation (de Araújo *etal*., 2010). Additionally, (Hadjigeorgiou *etal.*, 2000) discovered that sheep tend to drink about 15% more water than goats. When we look at how much water goats drink, it turns out they tend to take in less compared to sheep and other animals. This is largely due to how goats have adapted to survive in environments where water is scarce. Their adaptation is pretty much that of camels, animals that nobody can deny have the longest endurance of thirst in the desert being able to go for days without water. (Silanikove ,2000). Besides the efficient use of water that has always been a goat's selling point, their ability to not only reduce water loss through evaporation and feces but also to effectively concentrate their urine must be commended. Besides having evolutionary physical features allowing them to perform optimally with the least water, the physiological feature of goats being able to produce metabolic water though the breakdown of nutrients is also a major source of water for them. The approximate water released when 100 grams of carbohydrates are being oxidized is 60 grams. Similarly, the oxidation of 100 grams of protein yields around 42 grams of water, while oxidizing 100 grams of fat produces roughly 110 grams of water. However, it's important to note that there are some water losses during the oxidation process. In the case of fat oxidation, increased breathing can lead to greater water loss through the lungs, meaning that fat hydrolysis results in less metabolic water compared to carbohydrate hydrolysis (Esminger *etal*., 1990).

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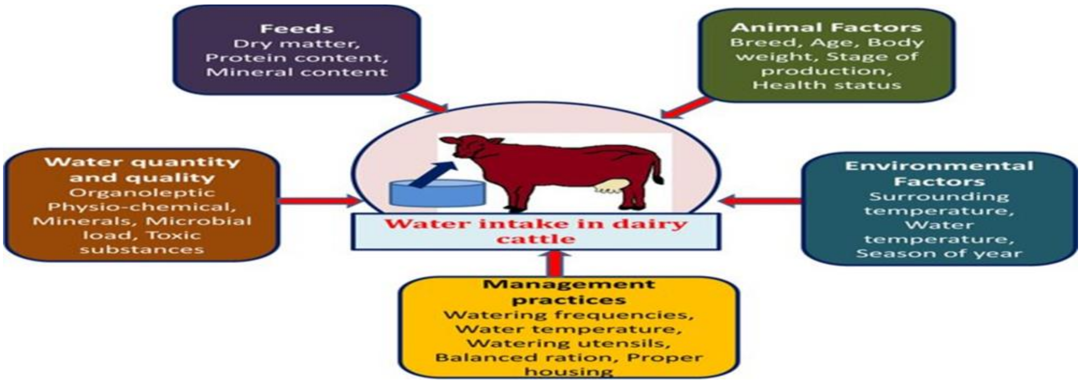

Singh *eta*l., 2022) (Factors affecting water intake in dairy cattle Figure 4.

Nutritional biotechnology: By utilizing advanced dietary techniques including probiotics, prebiotics, and phytogenic substances, nutritional biotechnology significantly improves ruminant health, productivity, and general well-being. These techniques aim to enhance the immune system and optimize the digestive systems of ruminant animals, such as sheep, goats, and cattle.

Probiotics: Probiotics are live bacteria that, when ingested in enough amounts by animals, boost the host's health. These benefits result from their capacity to boost the immune system and control the bacteria population in the gastrointestinal tract (Hotel and Cordoba,2001). Probiotics promote nutrient absorption, decrease harmful bacteria, improve fiber digestion, and balance the gut microbiota in ruminants Many kinds of bacteria, yeasts, and fungi, including Saccharomyces cerevisiae and Lactobacillus species, are commonly utilized probiotic species. These species are often added to yeast cultures, microbial mixtures, enzyme formulations, and other biological extracts (Güçlü and Kara,2009;Kumar *etal*., 2023). Probiotics are primarily used to boost the immune system, control the gut microbiota, and prevent the formation of harmful organisms (Markowiak, and Śliżewska,2017). Ruminants' plant diet primarily consists of complex carbohydrates that gastric enzymes are unable to break down, such as hemicellulose, cellulose, and lignin. Only different cellulolytic microbes in the rumen can break down these fibers. Probiotics aid in the growth of these organisms, which improves feed intake, rumen digestibility, and fiber degradation (Reuben *etal*., 2022). Probiotics also improve feed efficiency, dry matter intake, and the flow of nitrogen into the lower gastrointestinal tract while lowering the incidence of ruminal acidosis, according to several investigations (Khalid *etal*., 2011; Chaucheyras-Durand *etal.,* 2012 ; Bahari,2017). (Retta,2016) further detailed how probiotics assist the microorganisms that provide the intestinal tract with proteins, vitamins, and organic acids as well as the growth of adult rumen microbes, the fermentation process, and increased nitrogen transport to the intestinal system. Ruminants are predominantly animal whose diet consists mainly of plant material. Plant material refers to a large number of complex carbohydrates like hemicellulose, cellulose, and lignin, etc. which cannot be degraded easily by gastric enzymes under normal conditions. Only certain organisms living in the rumen are able to degrade these fibers. Probiotics encourage the growth of helpful organisms that help in the degradation of fiber, rumen digestibility and better feed intake(Reuben *etal*., 2022) .There are many studies (Khalid *etal*., 2011; Chaucheyras-Durand *etal*., 2012 ; Bahari,2017) which showed that, probiotics also reduce the incidence of ruminal acidosis, improve feed efficiency, dry matter intake, and flow nitrogen into lower GIT. (Retta,2016.) also reportedthat prebiotics help in increasing nitrogen passage to intestinal tract, growth of adult rumen microbes, rumen fermentation process and also favouring the microbes that provide proteins, vitamins and organic acids to the host. These were also reported in the probiotics report. Probiotics was 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 and He, 2018). Adding probiotics to feed improves both milk quality and amount, according to

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studies done by (Desnoyers *etal*., 2009). By improving digestibility and Feed Conversion Ratio (FCR) (Abd El-Trwab *etal.,* 2016), probiotics have a major influence on animal development performance as they boost average weight gained and growth rate. (Lesmeister *etal*., 2004) notes that improving total DM intake, daily hip height, daily hip width, and average daily body weight gain resulted from yeast (Saccharomyces cerevisiae) supplementation of calf diet. Maintaining meat color, pH, Water Holding Capacity (WHC), texture, tenderness, and enhancing its antioxidant qualities while lowering lipid peroxidation, probiotics were found to positively affect meat quality(Al-Shawi *etal*., 2020).

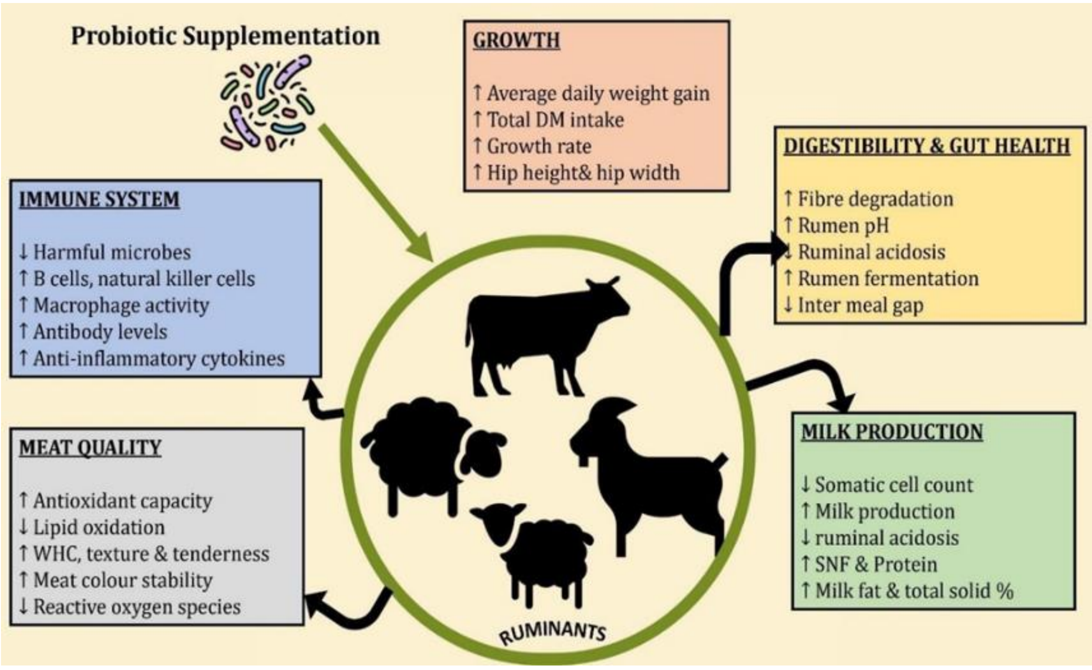

Fig 5: The role of probiotics supplementation in ruminant wellbeing(Devadharshini and Devamugilan ,2024)

Prebiotics : Prebiotics are non-digestible food components that increase the growth and activity of probiotic bacteria in digestive tract thus leading to improved health(Markowiak, and Śliżewska ,2017;Patel and Goyal,2012). In general, they are non-digestible compounds that stimulate the growth of some beneficial intestinal microorganisms (such as Lactobacillus spp., Bifidobacterium spp.) and have an inhibitory effect on pathogenic bacteria growth, composed by 3–10 monosaccharide(Morrison *etal.,* 2010). Several authors have shown that the addition of prebiotics in diet has positive effects on feed efficiency and growth with samong the negative impacts sucha s neonatal calf diarrhea threaten calves health development (Choct,2009; Ghosh and Mehla,2012;Heinrichs *etal*., 2013; Markowiak, and Śliżewska ,2017).This fact was related to the probiotic resist the colonization of pathogenic microorganisms and the probiotic improve the immune system (Morrison *etal.,* 2010 ; Walton *etal.,* 2013). Minerals like magnesium, calcium, and zinc are crucial in growth, development, and metabolic activities. Also, it is said that prebiotics are helpful in the absorption of these minerals (Scholz-Ahrens *etal*., 2007;Patel and Goyal., 2012).

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Phytogenic compounds: Bioactive phytochemicals such as polyphenols, essential oils, saponins and organosulfur compounds can be found in herbs and spices, in legumes and grasses, in tree leaves, in agro-industrial byproducts of plant origin(Kumar *eta*., 2023). They potentially affect rumen microbiota, they can decrease enteric methane production, increase nutrient assimilation and therefore enhance overall animal health and production (Tedeschi *etal*., 2021;Hassan *etal*.,2020 ; Vasta *etal*., 2019)For milk production, phytochemicals may effect fatty acid content and oxidative stability, whilst in meat systems they may be used as an antioxidant (improved shelf life) and also improve tenderness. Specifically for dairy systems, phytogenic feedstuffs increase milk yield and milk composition by increasing conjugated linoleic acids (CLAs), omega-3 fatty acids and antioxidant compounds in milk to result in a more nutritious milk with better oxidative stability. For meat system, these additions improve tenderness and flavor by improving oxidation and muscle metabolism.

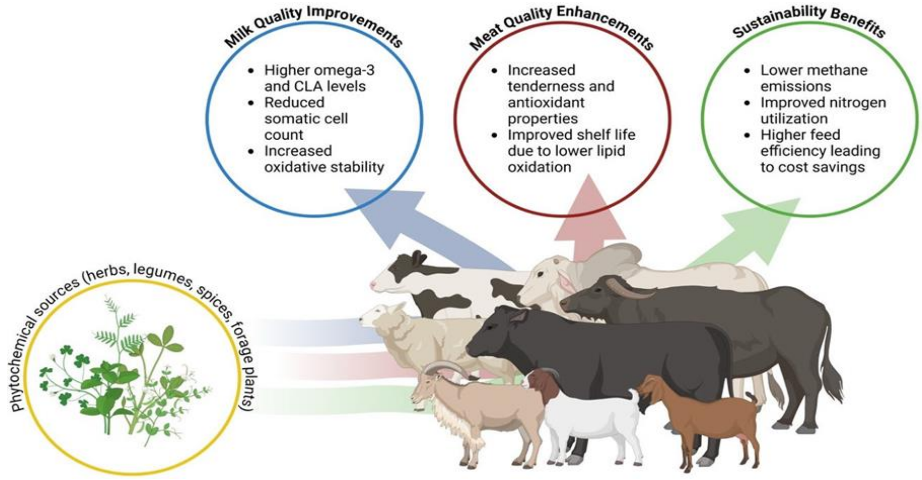

Figure 6. Effects of dietary phytochemicals on ruminant production, quality, and sustainability (Priyashantha *etal*., 2026)

Conclusion: Ruminants' nutrition allows the attainment of optimum growth, reproduction, milk and meat production, and functioning of other physiological activities related to general health. The review notes the inclusion of strategic dietary components such as proteins, minerals, vitamins, and feed additives; as well as feeding strategies such as supplementation and quality of forage; and how these are needed to optimize rumen fermentation, absorption of nutrients, immune response, and metabolism. The review describes advances in nutritional biotechnology, such as use of probiotics, prebiotics and phytogenics, which are of great promise to further improve the functions of the ruminants. The review emphasizes the importance of Customized nutritional plans designed according to the age, physiological state, and production objectives of ruminants toward successful ruminant management. The review notes that despite the level of knowledge acquired through research, challenges still exist in implementing that knowledge, particularly in developing countries. The review also emphasizes the importance of nutrition management in promoting the health and welfare of the ruminants, and the economic viability of the systems, as well as the contribution of ruminants to food production globally.

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