।पशुधनं नित्यं सर्वलोकोपकारकम्।

RECENT TRENDS IN ANIMAL HEALTH AND NUTRITION

NEW OPPORTUNITIES FOR SUSTAINABLE ANIMAL PRODUCTION

National Institute of Agricultural Extension Management (MANAGE), Hyderabad, Telangana

&

Rajasthan University of Veterinary and Animal Sciences (RAJUVAS) Bikaner

Recent Trends in Animal Health and Nutrition: New Opportunities for Sustainable Animal Production

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FOREWORD

Rajasthan University of Veterinary and Animal Sciences, Bikaner plays a significant role in Rajasthan's animal husbandry sector by providing education, research, and extension services. It focuses on improving animal health and livestock management and promoting sustainable practices to enhance the state's livestock economy. RAJUVAS also collaborates with various organizations to advance scientific knowledge and technology in animal sciences.

Sustainable animal production can serve as a tool to meet the world's growing demand for animal products while minimizing environmental impacts on the ecosystem. Good animal health and nutrition are crucial for sustainable animal production, promoting high productivity, efficient resource use, and reducing disease outbreaks, ultimately ensuring food security and livelihoods while minimizing environmental impact. Creating awareness about the different ways of sustainable animal production through such training programs is indeed a great initiative. I express my sincere thanks to the National Institute of Agricultural Extension Management, Hyderabad, especially Dr. Yogita Rana, Director General, MANAGE, Hyderabad, and Dr. Shahji Sambhaji Phand, Deputy Director, Allied Extension, MANAGE, Hyderabad for providing a platform to organize this training program at RAJUVAS, Bikaner.

The compilation of different lectures in the form of E-book on "**Recent Trends in Animal Health and Nutrition: New Opportunities for Sustainable Animal Production**" organized by RAJUVAS, Bikaner and MANAGE, Hyderabad from 26th to 28th July 2023 in the form of the present E-book will serve as a guide and reading material for students and researchers in the field of Animal Health in general and animal nutrition in particular. I am sure that this compilation will help readers to update their knowledge about emerging concepts of sustainable animal production and its role for ensuring improved production and animal welfare.

I compliment Prof. R.K. Dhuria, Course Director and Dean, PGS, RAJUVAS, Bikaner, and his team for publishing this E-book.

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PREFACE

The compilation of training lectures, **"Recent Trends in Animal Health and Nutrition: New Opportunities for Sustainable Animal Production,"** brings together the collective expertise of leading scientists, practitioners, and industry leaders. It is designed to serve as a comprehensive resource for veterinarians, animal nutritionists, extension officers, researchers, and students who are committed to advancing sustainable practices in animal agriculture. The lectures explore cutting-edge topics such as precision nutrition, alternative protein sources, feed additives for gut health, nutritional genomics, and digital innovations, all within the broader context of sustainability and One Health.

The topic Recent Trends in Animal Health and Nutrition: New Opportunities for Sustainable Animal Production is of utmost importance of the day as the landscape of animal health and nutrition is undergoing a remarkable transformation, driven by mounting global challenges with climatic changes. As the world's population continues to rise, so too does the demand for animal-derived food products, placing unprecedented pressure on our natural resources and production systems. In this context, the pursuit of sustainable animal production is not merely an aspiration—it is an imperative for ensuring food security, safeguarding public health, and protecting our environment for future generations.

I extend my sincere gratitude to Prof. Manoj Dixit, Hon'ble Vice-Chancellor, RAJUVAS, Bikaner for his constant support, encouragement, and guidance for organizing different educational training programs in the University. I am thankful towards National Institute of Agricultural Extension Management (MANAGE), Hyderabad for generously supporting the training program and for publishing this E-book. I would like to thank all the contributors and organizers whose dedication and insights have made this e-book possible. I also acknowledge other editors of this E-book Dr. Deepika Dhuria, Dr. Jagriti Srivastav, Dr. Shahji Sambhaji Phand and Dr. Sushrirekha Das. It is my hope that this compilation will inspire new ideas, foster collaboration, and equip readers with the knowledge and tools necessary to navigate the evolving landscape of animal health and nutrition.

(R.K. Dhuria)
Dean PGS

Preface

The livestock sector plays a pivotal role in ensuring food security, improving rural livelihoods, and contributing to the national economy. In the face of rising demand for animal-derived foods, climate change, and emerging health challenges, it is imperative to adopt innovative and sustainable approaches in animal health and nutrition. This book, *"**Recent Trends in Animal Health and Nutrition: New Opportunities for Sustainable Animal Production**",* is a joint initiative by the National Institute of Agricultural Extension Management (MANAGE), Hyderabad, and Rajasthan University of Veterinary and Animal Sciences (RAJVASU), Bikaner, aiming to provide a comprehensive understanding of the latest advancements in the field.

The chapters in this volume, contributed by leading researchers, academicians, and field practitioners, explore a range of contemporary topics including precision nutrition, alternative feed resources, probiotic applications, disease diagnostics, zoonotic risk management, and climate-resilient livestock practices. Emphasis has also been laid on indigenous knowledge, policy frameworks, and the role of digital technologies in transforming animal husbandry.

This compilation is intended to serve as a reference for veterinary professionals, animal nutritionists, researchers, students, extension personnel, and policymakers engaged in the pursuit of sustainable animal production systems. We hope the insights and recommendations presented in this book will inspire innovative thinking and informed decision-making in animal health and nutrition management.

We extend our sincere gratitude to all contributors, reviewers, and the institutions involved for their valuable efforts in bringing this publication to fruition. Special thanks are due to the leadership at MANAGE and RAJVASU for their continued support and encouragement in fostering collaborative knowledge exchange.

Editors:

R.K. Dhuria,
Deepika Dhuria,
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Chapter-1

Low Fat and Solid not Fat in Milk of Dairy Cows: Reasons and Remedies

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Introduction:

Dairy activities in the last few decades with crossbreeding, better health care and management have made India to occupy the first position in milk production. More than 75% of the milk production in India comes from small and medium livestock holding sector. Feeding accounts for about 70% of the total input cost and hence any improvement in the nutrition of dairy cattle will have positive impact on productivity and quality of milk. Quality of milk in terms of optimum fat, solid not fat (SNF), minimum microbial load, devoid of contaminants and endogenous toxins is very important to meet the standards and also to compete in open market.

Milk Quality:

Fat and SNF in milk are controlled by genetic factor. Other reasons for low milk fat are: low fibre intake (fodder), feed particle size- too coarse or too fine, more soluble sugar intake, excessive content of fats in diet, less protein and sulfur deficiency in diet, early stage of lactation, hot and humid climate, faulty milking methods, faulty milk testers, and also sometimes due to adulteration. Low SNF is generally due to inadequate intake of fermentable fibre along with protein, inadequate rumen bypass protein. Feeding of sufficient green fodder along with balanced concentrate mixture in the form of total mixed ration will help to overcome both the problem of low fat and SNF in milk of dairy cows.

Reasons for Low Milk Fat:

Genetics:

Low milk fat is not every farmer’s problem. The Holstein Freisen (HF) pure and its crosses are genetically prone for less milk fat as compared to Jersey and indigenous dairy animals. Milk fat is inversely related to milk yield and high milk yielding cows tend to have less milk fat. In early lactation during peak milk yield, milk fat will be generally low (Less than 3.5%).

HF Cow

Jersy Cow

Low Fiber/Fodder Intake:

Inadequate intake of fodder either green or dry fodder will result in low acetate and butyrate production in rumen and hence low milk fat synthesis. Minimum 30% fibre (Neutral detergent fibre) in the whole dietary dry matter is required. Green fodder (dry matter) intake should be at least 1% of body weight of the animal. Ex. 400 kg body weight, 4 kg dry matter through green fodder, i.e. fresh basis about 25 kg green fodder per day per animal. Chaff the fodder to about 1–2-inch length and feed. Too much fine grinding of feed results in low milk fat and SNF due to inadequate rumen fermentation and low rumen microbial protein synthesis. Supplementation of legumes and tree leaves along with dry fodder will improve milk quality both in terms of fat and SNF.

Green Fodder and Dry Fodder – Source of Fiber

More Concentrate or High Soluble Sugar Intake:

Intake of more concentrate or grains (maize) with low fibre intake will result on more lactate and low milk fat. Hence fibre and concentrate should be balanced and fed. In most instances, a Non fibre carbohydrate between 35% to 40% is considered ideal. First feed chaffed fodder and next concentrate for better fibre digestion in rumen. Rumen buffers, such as sodium bicarbonate ($NaHCO_3$: 50 gm per day) and magnesium oxide (MgO: 15 gm per day), are known to correct the milk fat depression observed on restricted fodder rations by increasing dry matter digestion. MgO supplementation increases triglyceride uptake by the mammary gland.

More Concentrate and Grains in Ration: Cause of Low Milk Fat

Subclinical Rumen Acidosis:

When fed with more cereal grains or fermented product, it causes rumen acidosis. Prolonged such incidences would lead to laminitis in dairy animals. Prolonged feeding of silage alone as a sole source of fodder will also lead to sub clinical rumen acidosis, laminitis and low fat in milk. Hence, silage should be fed along with concentrate mixture in the form of total mixed ration, mixing with other fodder. During peak lactation, when the diet has more grains, feeding of sodium bicarbonate (50-100 gm) is recommended.

Excessive Fat and Oil Intake:

Combination of high grain and high unsaturated fatty acids in the diet causes the microorganisms in the rumen to produce more Trans fatty acids. Some of these Trans fats have suppressive effects on fat synthesis in the mammary gland. Low fodder, high concentrate diets cause the rumen fluid to be more acidic, which alters the microbial population because some bacteria are sensitive to acidic conditions. The shift in rumen microflora favours accumulation of Trans fatty acids that can depress milk fat synthesis after absorption into the blood. Feeding of too much fat or oil will depress rumen fibre digestion and hence low fat in milk. But in Indian conditions this situation is not common.

Protein and Sulfur Deficiency:

Low protein and sulfur intake reduces rumen fermentation and reduces both milk fat and SNF. Feed adequate protein through concentrate mixture or legume fodders. Low milk SNF is mainly due to low protein intake and also inadequate rumen bypass protein intake. Concentrate mixture of high yielding dairy cows should have atleast 50% rumen bypass protein to get desired SNF in milk. Inclusion of cotton seed meal, legume fodders, tree leaves will supply quality bypass protein.



Cotton seed Meal, Coconut Meal and Legume Greens: Source of Bypass Protein

Sequence of Feeding Fodder and Concentrate:

Feeding of fodder causes salivation and has a buffering action in rumen. On the other hand, feeding of concentrate before fodder could lead to acidic condition in rumen, resulting in reduced digestion. Hence feed first chaffed fodder followed by concentrate for better rumination, rumen microbial activity and animal health. Feeding the mixture of fodder and concentrate is the better option.

Urea-Energy Enrichment of Dry Fodder:

Dry fodders like paddy straw/ragi straw, maize/jowar kadbi can be chaffed and sprayed with solution containing urea and molasses (urea 200 gm, molasses/jaggery 400 gm, dissolved in 2.0 (two) liter water for 10.0 (ten) kg dry fodder, mixed properly and feed to adult cattle. The nutritive value of this enriched dry fodder is almost equal to medium quality green fodder and support optimum rumen digestion. Precaution should be followed while using urea as nitrogen source for adult ruminants.


Total Mixed Ration (TMR):

In TMR, all the ingredients (roughage, concentrate, supplements) are mixed and offered to the animal. It ensures that the concentrate intake is spread uniformly over the day rather than only twice daily in the conventional feeding system. This enhances the digestibility of roughages, reduces the nutrient loss and results in increased rumen microbial protein synthesis and thereby improve the productivity and profitability. Preparation of TMR comprising of roughage / forage, concentrate and other supplementary nutrients in required proportion made into uniform mixture either in the form of mash or pellete (complete feed).

Total Mixed Ration for Better Rumen Function

Season of the Year:

In hot climates, the summer months typically result in depression in milk fat concentration. Although the exact mechanisms are not entirely clear, it is thought that reductions in milk fat during hot months are the result of changes in eating patterns of dairy cows and reduced buffering capacity of saliva because of panting. It is also possible that increased body temperature during heat stress might have a direct effect on fat synthesis by the mammary gland. Therefore, proper cooling of cows is critical for producing milk in hot environments. This requires shade, forced ventilation, and evaporative cooling. Supplementation of 50 gm mineral mixture and 50 gm baking soda per day along with concentrate mixture will help to solve this problem.

Managemental Factors:

Avoid mixing of concentrate mixture in water. If required it can be in semi-solid form but not in semi-liquid form. Best is just sprinkle water to concentrate mixture to avoid dustiness. After feeding concentrate mixture, avoid giving drinking water for at least 2 hours, so that rumen digestion of concentrate will be better. Last drops of milk from udder have more fat and hence complete milking should be done. Milk should be kept in cool place and thoroughly mixed and homogenized before analysis for fat and other factors. Adulteration of milk with water should be penalized and incentives for good quality milk should be provided.

Conclusion:

Low milk fat and SNF are governed by genetic, nutritional and managemental factors. High yielding dairy cows during early part of lactation are prone for this problem. Feeding good quality green fodder with legumes and balanced with concentrate mixture is key to solve this problem. Better fermentation of nutrients in rumen through feeding total mixed ration helps in improved fat and SNF.

Chapter-2

Rumen Manipulation: An Important Strategy to Improve Livestock Productivity

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Introduction:

The ruminants have got unique ability to utilize the poor quality of feed and fodder for their body maintenance and also for the production of meat and milk used for human consumption. This ability in ruminants is due to specialized stricture of their gastro intestinal tract. Their stomach has four compartments consisting of rumen, reticulum, omasum and abomasum. The rumen is located at the beginning of the tract and plays a major role in feed digestion as around 50% of the digestion takes place in this region. In the rumen a vast microbial community is present which helps in the fermentation of lignocellossic feed. The rumen microbial ecosystem is an efficient anaerobic fermentation system and has advantages over monogastric animals in following ways: 1. The ruminants can use non protein nitrogen sources to meet part of their protein requirement, 2. They can digest large amount of ligno-cellulosic feeds, 3. The ruminants can also detoxify many toxic ingredients present in feeds. The microbial consortia present in the rumen helps in the extraction of energy from the roughage consumed by the animals but the extraction of nutrients is not optimal and still there is a scope to improve as 40-60% nutrients consumed by the host goes unutilized as waste in the form of faeces. There is ample scope to improve the utilization poor quality roughage and also for higher microbial protein production in ruminant's trough manipulating rumen microbial ecosystem.

Important Areas of Rumen Manipulation:

Some of the important areas where the manipulation of rumen fermentation can be done are listed here.

- To increase the utilization of lignocellulosic feeds.
- To reduce methanogenesis.
- To prevent acidosis condition in ruminant.
- To detoxify the plant toxins present in feed and fodders.
- To increase the microbial protein synthesis in the rumen
- To improve the quality of livestock product

Improving Fibre Digestibility:

The activity of microcrystalline cellulase (a key enzyme for the degradation of crystalline cellulose) is very low as compared to endoglucanase activity (act on amorphous cellulose) and it has been reported that by increasing the fibre in the diet, the activity of microcrystalline cellulase decreased (Kamra *et a*l., 2003). To improve the fibre degradation, the use of isolates from the rumen with high cellulase activity can be used as feed additive. The administration of an anaerobic fungus, isolated from goats, to sheep resulted in an increased digestibility and intake of lignocellulosic feed. Administration of encapsulated culture increased the growth performance of buffaloes significantly.

Reducing Methane Production:

In the rumen, nitrate reducing bacteria and sulphate-reducing bacteria, in addition to methanogens and homoacetogens, utilize hydrogen as a substrate for growth. Many genera of this bacterial group can catalyze all reactions of the nitrogen and sulphur cycle as they remove oxygen and hydrogen from the gut ecosystem, produce acetate from propionate and hydrogen sulphide, and some isolates can oxidize sulphide to sulphate and prevent accumulation of toxic levels of hydrogen sulphide. Nitrate is degraded by nitrate reducing bacteria to ammonia. The nitrate reducing bacteria were isolated from the rumen of buffalo and have shown ability to reduce methane production under in vitro condition (Sakthivel *et al*., 2010). The sulphate reducing bacteria have also been isolated and have been evaluated under in vitro for their potential to reduce methane emission by ruminants.

Controlling Acidosis in the Rumen:

The important bacteria which produce lactic acid on carbohydrate rich diets are the strains of *Streptococcus bovis* and *Lactobacillus*. The accumulation of lactic acid in the rumen of such high concentrations results in a decline in pH, a reduction in fibre degradation and leads to acidosis in the rumen. The problem of acidosis can be tackled by inducing the growth of lactate utilizing bacteria in the rumen e. g. *Selenomonas ruminantium* and *Megasphaera elsdenii.* These bacteria are able to utilize 95-100% of lactate formed during fermentation. *M. elsdenii* converts lactate to propionate and acetate by the acrylic acid pathway. *Wolinella succinogenes* has a unique property of using intermediate fermentation products as energy source, e.g. formic acid and hydrogen are oxidized with simultaneous reduction of malic acid or fumaric acid to succinic acid. Nitrate is reduced to ammonia. The reduction of above acid with hydrogen oxidation, serves as an alternate hydrogen sink in the absence of methanogenesis due to either use of antibiotics or defaunation.

Feed Toxin Degradation:

The mimosine, an amino acid found in *Leucaena leucocephala* is converted by to the toxic goiterogen 3-hydroxy-4(1H)-pyridone (DHP). A new bacterial species, *Synergistes jonesii* is capable of metabolizing DHP of soobabool. This metabolically specialized bacterium capable to grow only on DHP. Cultures of this organism have subsequently been used as inoculants to protect ruminants in other parts of the world from mimosine toxicity (McSweeney, 2011). The oxalate degrading bacteria in the rumen is not very high (about 1-10 million cells/ ml of rumen liquor) but on increasing dietary concentration of oxalate helps in selective growth of oxalate degrading bacteria and therefore, the animals are able to tolerate high levels of oxalate. The oxalic acid can be metabolized by *Oxalobacter formigenes* to formic acid and CO_2 (Allison *et al*., 1985). Degradation of fluoroacetate by rumen microbial community is another important success story of toxin degradation by rumen microbes. This compound, present in some tropical forages and is toxic to mammals via its conversion to fluorocitrate, an inhibitor of aconitase, a key enzyme in the citric acid cycle. Gregg (1995) has reported the introduction, into *Butyrivibrio fibrisolvens* OB156, of a plasmid containing a gene for hydrolytic ehalogenation of fluoroacetate. The plasmid was stably maintained in this strain in vitro, and the bacterium was maintained in measurable numbers for over 5 month following inoculation into the rumen of sheep.

Improving Tannin Rich Feed Utilization:

The degradation of tannins in the rumen is not very common as these are polymers of phenols and their derivatives. The first report of bacteria degrading tannic acid-protein complex is (Osawa and Mitsuoka, 1990) who described the isolate as *Streptococcus bovis* from deer. *Streptococcus caprinus* has also been isolated from the rumen. The tannins degrading bacteria were also isolated from migratory goat by Singh *et al*., (2011). Chaudhary *et al*., (2011) used the best tannin degrading bacterial strain of previous study for the feeding of goats getting tannin rich feed but no beneficial effect of probiotic feeding on feed digestibility was found.

Improving Microbial Protein Synthesis in the Rumen:

The rumen microbial protein represents a major source of amino acids to the ruminants. It accounts about 75% of the total amino acids absorbed by ruminants. The daily microbial protein synthesis is the product of the efficiency of microbial protein synthesis, which usually is defined as grams of microbial crude protein (MCP)/ kilogram or 100 grams of organic matter (OM) digested in the rumen). The efficiency of microbial protein synthesis varies in animals with different diets fed. The mean efficiency of microbial protein synthesis is 14.8 g MCP/100g of OM truly digested in the rumen. The factors, which affect microbial protein synthesis in the rumen, are given below:

- Dry matter intake
- Availability of nitrogen compounds
- Availability of fermentable energy

- Ratio of forage: concentrate
- Rumen environment
- Matching the release of nitrogen and energy in feeds
- Flow rate of digesta
- Minerals and vitamins

Modification of Rumen Fermentation for Enhanced CLA in Animal Product:

The biohydrogenation of unsaturated fatty acids in the rumen is an important process and it affects the fatty composition of ruminant products. Several efforts have been made in this direction to change the composition of ruminant products to get healthier products for human consumption. Dietary manipulation of ruminant's diet containing oils rich in unsaturated fatty acids were tried by researchers. Use of encapsulated oils, to bypass it from ruminal biohydrogenation, fish oil, monensin etc. can be tried to alter the biohydrogenation in the rumen. It is now established that diet of animal plays very important role in determining the quality of livestock product and its manipulation offers great potential in changing the composition of milk and meet of desired quality. The research on fatty acid biohydrogenation in the rumen is intensified and the discovery of conjugated linoleic acid (CLA) as having potential health benefit for human as well as animal has attracted the attention of researchers to enhance its concentration in animal product. The CLA content of ruminant product such as milk and meat can be modify up to great extent through dietary manipulation.

Conclusion:

The rumen microbial ecosystem can be manipulated to obtain the desired goal in livestock production system. With the advent of advanced technologies, the information on the rumen microbial ecology are being generated at a faster rate. In future the new information generated will be helpful in getting improved and economic livestock farming.

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Chapter-3

Advances in Feeding Management of Periparturient Dairy Animals

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Introduction:

The periparturient or transition period describes the change from a non-lactating cow to a lactating cow after parturition. As such, it is usually considered to extend from about 3 weeks before calving to about 3 weeks post-calving. The peripartum period is the most challenging time for the dairy cows considering the cascade of nutritional and physiological changes associated with the late pregnancy, parturition and onset of lactation. The mid dry period is considered to be a resting stage between two lactations with low nutrient requirements, but as parturition approaches marked changes in hormonal status to accommodate parturition and lactogenesis occur. A high incidence of metabolic diseases, like ketosis, hypocalcemia and infectious diseases, e.g., mastitis and endometritis, occurs in early lactation. Thus, the transitional period needs to be cautiously observed regarding factors such as management, adequate feed composition, e.g., the balance between energy and protein, adequate micro-nutrients supplementation, and feeding practices to make the transition from the dry to the post-partum stage as smooth as possible.

Metabolic Status of the Transition Cow:

The late pregnancy period is a period of metabolic transition. The transition involves alterations in adipose tissue, liver, and skeletal muscle metabolism and several hormonal changes that are involved in initiation of parturition and initiation and maintenance of milk production. As parturition approaches, plasma growth hormone increases and plasma insulin decreases. Plasma estrogen increases during late gestation with a rapid increase just before calving and then decreases at calving. Progesterone levels remained high until about day 250 of gestation and then decrease until calving. A four-fold increase in glucose requirements has been reported in high yielding dairy cows at the beginning of lactation compared to non-lactating cows. The main substrate for the synthesisof glucose is propionate from microbial fermentation of feed carbohydrates. Though, particularly in early post-partum as a consequence of inadequate DMI and high need of glucose, the cows are also dependent of endogenous substrates, mainly glucogenic amino acids (glutamine, alanine) from degraded endogenous protein sources, and glycerol from adipose tissue mobilization.

In the pre-partum period, energy demands exceed dietary energy supply due to increased demands of the growing fetus and a reduction in feed intake. This leads to adipose tissue mobilization, mediated by enhanced lipolysis and reduced lipogenesis. Lipolysis results in the release of non-esterified fatty acids (NEFA) into the bloodstream. The NEFA can then be taken up by organs such as the mammary gland or liver and be incorporated into milk fat or used as an energy source. When the NEFA are extracted by the liver they can be oxidized to completion, partially oxidized to ketone bodies or esterified to form triglycerides (TG). The ruminant liver has a limited capacity to remove TG, hence, if the cow mobilizes a lot of body fat, the TG accumulate in the liver leading to the condition of fatty liver. Fatty liver appears to be a predisposing factor for the developmentof ketosis. Ketosis resulting from the excessive production of ketone bodies, can have negative effects on the immune response. Hormonal changes associated with parturition may be involved with the increase in liver TG levels in the periparturient period. The level of plasma estrogen of placental origin increases as parturition nears. The peak in estrogen may promote fatty acid mobilization from adipose tissue during late pregnancy independent of any change in feed intake and energy balance.

Periparturient Diseases vis-a-vis Nutritional Physiology:

Acidosis and Laminitis:

During dry period cows are usually shifted to a high forage ration,which is less in energy and more in fibre relative to an energy-dense lactation ration. Ultimately when the cow is shifted abruptly to a high energy lactation diet, it becomes at high risk of developing rumen acidosis, because while the lactate producers respond immediately to high starch diets and produce higher amounts of lactate, the lactate utilizers respond more slowly. At this point the population of protozoa and many of the bacteria are killed or inactive. The resultant endotoxins and histamine released from the dead rumen flora along with lactic acid are absorbed systematically and affect the microvasculature of the hoof wall, which can then result in clinical laminitis.

Abomasal Displacement:

With the advance of pregnancy, the growing uterus occupies an increasing area of abdominal cavity. The uterus begins to slide under the caudal aspects of the rumen, forcing abomasum forward and slightly to the left side. After calving, uterus retracts back towards the pelvic inlet but instead of returning to its normal position, the abomasum may sometimes get displaced to the left side of the cow. Decline in plasma calcium level around parturition linearly decreases abomasal contractility, which is suspected to lead to atony and displacement of the abomasum. Presence of VFA within abomasum also reduces abomasal contractility, which is often facilitated by a high grain-reduced forage diet.

Ketosis:

During early lactation, the amount of energy that is required for maintenance of body tissues and milk production exceeds the amount of energy the cow can obtain from dietary sources. Consequently, the cow must utilize body fat as a source of energy. Though, the capacity of the liver to completely oxidize the fatty acid (via tricarboxylic acid cycle) and export (as very low-density lipoprotein, VLDL) is limited. Once this limit is reached, triglycerides accumulate within the hepatocytes, impairing their function, and the acetyl coenzyme A that is not incorporated into tricarboxylic acid cycle is converted to acetoacetate and β-hydroxybutyrate. The appearance of these ketone bodies in the blood, milk, and urine is diagnostic of ketosis and usually become clinically evident between 10 d to 3 weeks post-calving. The cow becomes hypoglycemic and depressed with reduced feed intake and milk production.

Retained Placenta:

Numerous factors are thought to be important in determining whether the placenta is successfully expelled. Dietary deficiency of Se has also been implicated as one of the important factors in retained placenta. A great deal of epidemiological evidence exists that links milk fever with an increased incidence of retained fetal membranes. The plausible explanation is that hypocalcemia presumably prevents the uterine contractions that are necessary for expulsion of the placenta. Another theory to explain the incidence of retained placenta has been linked to the immunosuppression usually observed at calving. The post-partum immunosuppression has been linked to various endocrine and nutritional factors. Increased plasma levels of estrogen and cortisol can be correlated as the causative agents of the immunosuppression observed at calving. Because oestrogens have a strong immunosuppressive effect on cell-mediated immunity and glucocorticoids have long been used as powerful immunosuppressive agents.

Mastitis:

During the first week of dry period, when the milk flow ceases to flush the invading bacteria from the streak canal, a high proportion of intra-mammary infections occur in the involuting gland. However, these subclinical infections are most likely to flare up during the first month of lactation which could, partly at least, be answered by the periparturient immunosuppression observed at calving. As the mammary secretion change to colostrum, lactoferrin concentration declines, facilitating thereby bacterial growth. The keratin plug that seals the teat during the first week of dry period breaks down about 7-10 days before parturition, permitting bacteria easier access to the gland. Moreover, the periparturient hypocalcemia, which is quite common at calving, is suspected to impair the smooth muscle contraction that is vital to the closure of the teat sphincter after milking.

Hypocalcemia:

The onset of lactation puts such a large demand on the mechanisms of Ca homoeostasis that most cows develop some degree of hypocalcemia at parturition. In some cases, plasma Ca levels become too low to support the neuromuscular function, resulting in parturient paresis or milk fever.

Feeding Management of Periparturient Cows:

For effective prevention of periparturient disease and increase the potential for successful reproduction, there are five critical control points during the transition period that need to be given attention viz. (i) improve DMI (ii) stimulating rumen papillae development (iii) reducing negative energy and protein balance (iv) maintaining Ca homeostasis and (v) avoiding immune system dysfunction.

Increasing Dry Matter Intake:

Cows that experienced periparturient disease have been shown to a more decline in DMI. DMI normally declines between 5 and 30% during the final 2-3 weeks of gestation. The severity and duration of the decline in DMI depends on many physiologic and metabolic. In addition, other factors including diet composition, pregnancy status, social interactions and environmental conditions may further influence actual DMI in late pregnancy. Increasing pre-partum DMI besides preventing periparturient disease, may help to accelerate DMI post-partum.

Stimulating Rumen Papillae Development:

Rumen papillae help to maintain acid-base balance in the rumen by absorbing VFAs, particularly lactate. Growth of these papillae is influenced by propionate and butyrate, but not acetate. High fiber dry cow diets predominately produce acetate during fermentation, which results in a reduction in papillae length. Adding fermentable nonstructural carbohydrates (starch) to the late gestation diet can have positive effects by initiating rumen papillae growth and allowing rumen organisms to adapt to the starch substrate. Having the rumen papilla adapted to a prepartum grain diet would facilitate the transition to a high grain lactation diet. This would possibly allow the cow to increase DMI more rapidly post-partum and minimize the disease problems associated with ruminal acidosis and displaced abomasum.

Control Negative Energy and Protein Balance:

The energy intake must not be compromised during the day before calving in order to prevent occurrence of ketosis. Provision of high energy low fibre diet, allowing for proper adaptation period to avoid acidosis, would reduce the methanogenic bacteria increasing thereby the energetic efficiency of the diet. Feeding other gluconeogenic precursors such as propylene glycol has also shown positive effects on energy status of the late pregnant cow.

Feeding of fat in the pre-partum diet has been shown to improve energy status and prevent hepatic lipid infiltration. The tactic hence should be (i) increase dietary energy and protein density in the dry diet (ii) use carbohydrate and protein sources to ensure suitable amounts of RDP and UDP (iii) use good management practices to improve DMI.

Maintain Ca Homeostasis:

A periparturient disease most commonly linked with macro-mineral nutrition is parturient hypocalcemia. The underlying pathogenesis has been related to a failure of the Ca homeostatic system to maintain blood Ca levels with the onset of lactation. Kidney and bone are the target organs of concern, which are unresponsive to parathormone stimulation. More recently, dietary K and Na rather than Ca have been implicated as primary inducers of milk fever. High dietary K not only interferes with Mg availability, but also contributes to metabolic alkalosis, which hinders target organ response to the Ca homeostatic system.

Minimize Immune Dysfunction:

The immune system of dairy cow has been shown to decline in responsiveness during transition period, possibly a result of increased cortisol secretion associated with calving. A negotiated immune system may lead to high incidence of metritis, mastitis, or other infectious disease. It is thought that hormonal and metabolic factors may play a primary role in this physiologic immune suppression, it can be further suppressed by nutritional insults. Energy, protein, micro-minerals and fat-soluble vitamins are all potential nutritional mediators of immune function. The approach should be (i) trace minerals 20-50% above than NRC (ii) vitamin E to 4,000 IU/d in close-up period and 2,000 IU/d in early fresh period.

Conclusion:

The dietary management to decrease the occurrence of periparturient disease and thus optimize the production and reproductive health of dairy cows should aim adaptation of rumen to lactation diet, abolition of hypocalcemia and immunomodulation to stimulate the immune system at calving. A suitably managed pre-partum feeding approach would lead to a number of potential benefits in the close-up dry period including increased milk production in early lactation, improved ability to cope with high concentrate post-calving diets, leading to better cow health-reduced acidosis, ketosis, displaced abomasum, improved fertility and better calf health and performance.

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Chapter-4

Innovative Feeding Strategies for Optimum Sheep and Goat Production

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Introduction:

Small ruminant farming plays a crucial role in providing nutritional and socio-economic security to millions of landless, marginal and small farmers who prefer low-investment ready marketable sheep and goat rearing compared to high investment in cattle and buffalo rearing. They contribute largely to the agrarian economy, especially in areas where crop and dairy farming are not economical, and play an important role in the livelihood of a large proportion of landless as well as small and marginal farmers. Sheep and goats are quite diverse in terms of genetic potential, distribution, function and productivity and are considered the most efficient transformers of low-quality forage into high quality animal products (Sahoo et al., 2019). Application of innovative feeding strategies focus on optimizing feed intake, utilizing alternative feed sources, and enhancing nutrient availability. These strategies can improve animal productivity, reduce carbon footprints, and improve the quality of meat and milk. Invariably, small ruminant husbandry faces several constraints being always at the receiving end in competition with other animal species and suffer more due to feed and fodder crisis. Therefore, most often they forced to thrive on traditional and most prevalent (75-80%) low input-low output grazing and browsing system (Sahoo, 2023). On the contrary, medium input-moderate output and high input-high output feeding systems are also needed to augment animal protein availability through its meat and milk for the increasing human population. This throws challenges to explore innovative feed formulations utilizing more economical locally available feed resources, strategic supplementation at different stages of growth and production (reproduction), feed processing technologies to ensure round-the-year adequate feed and nutrient supply and application of artificial intelligence (AI) for optimizing production (Sahoo and Anandan, 2024). Some of the key innovations in sheep and goat nutrition and feeding are:

i) Ensuring colostrum feeding and enhancing its quality;
ii) Pre-weaning adequate suckling from mother or milk feeding;
iii) Creep feeding;
iv) Concentrate supplementation;

v) Feeding basal feed (forage resources);

vi) Stall feeding vs grazing;

vii) Breed-specific/production-oriented feeding;

viii) Ensuring quality forage;

ix) Alternative feed resources;

x) Harnessing positive effect of plant phytochemicals;

xi) Utilizing herbage rich in poly-unsaturated fatty acids (PUFA);

xii) Different nutritional models for recording feed and nutrient input;

xiii) Models studying per animal/whole farm output;

xiv) Automation in feeding and application of AI for optimizing production.

Identifying Constraints:

Identification of constraints in sheep and goat productivity and the inclusion of women in the development of need-based technologies and training programs are key factors in an effort to achieve improved small ruminant production, increase food security, and enhance rural livelihoods. Further, the problem-specific research and development programmes should be prioritized to improve income and nutrition of small ruminant farmers. Thus, there is a need for concerted efforts on intensification of transfer of technologies and delivery of extension services on improved sheep and goat production and management practices with a convenient access to resources, technologies and markets. There is also a need to improve efficacy of institutional mechanisms including reforming livestock markets, strengthening veterinary care systems with improved man power, efforts to conserve pasture land and improve its productivity, and, channelling greater credit and insurance coverage for the small ruminant sector.

Feeding and Nutritional Strategies:

Improvement of nutrition efficiency in sheep and goats is more challenging than for other species. Because of their nutritional and environmental adaptability, sheep and goats are reared in very diverse farming (from extensive to highly intensive) and feeding (from grazing and browsing to total mixed diets) systems, in wide-ranging geographical areas and by using different breeds, populations, and crosses. In commercial production, nutritional input-output ratio is considered one of the major determinants for assessing profitability in any livestock husbandry system due to lion-share (up to 70%) involved in cost of feeding and nutritional supplements (Sahoo et al., 2015). Therefore, net return and cost: benefit ratio decides profit making and future expansion of this entrepreneurship. Availability of resources and judicious use of the same through feed banking is essential for year-round feed and nutrient supply without incurring drop in production due to periodic scarcity or calamity. Nutritional immunization against production decline is invariably dependent on three following approaches:

- Evolving a module simulating commercial sheep production involving two and three tier agro forestry production system.
- Fodder maximization and quality improvement adopting environment friendly agronomic practices and its effect on nutrient utilization in sheep.
- Exploring newer feed resources for sheep feeding and evolving farmers' friendly conservation techniques
- Feed banking to ensure round the year feed and nutrient supply and to put a check in production decline in the event of scarcity/calamities

Both the surplus conventional and unconventional feed can be stored in the bank by making good quality silage, feed pellet, feed blocks, etc. (Sahoo, 2019b; Sahoo, 2021). The model involves people's participatory programme (PPP) to establish a feed bank at 'Village' or 'Panchayat' level with due support from 'The Government'. It can act as a 'Bank' for storage of surplus resources at farmer's hand and distribute the concentrate supplements or total mixed ration in exchange of the available resources deposited. The Government of India programme, 'MGNREGA' that is targeted at providing job opportunities can be extended to village pasture and forest development with due emphasis on feed banking. The silage may be feed to the animal during the scarcity of water and food. It can be effective in improving feed quality in extreme climate change area.

Commercial sheep and goats farming involving challenge feeding of weaner lambs/kids to harvest maximum finishing weights will meet out the demand driven animal protein need of the increasing human population. The concept of 'Cafeteria feeding' allows free access to the lambs/kids to meet adequate energy and protein for the early growth phase in most efficient manner. Chaudhary et al. (2015) assessed the influence of on-farm supplementary feeding of concentrate pellets to Sirohi goat kids (60 d old) maintained either on 6h sole grazing (control; n=5) or grazing with supplementation at 1.5% of live weight for 140 days and found finishing weight of 25.8 kg versus 12.08 kg. There was improvement in carcass yield with promising dressing percentage. In this line, many commercial entrepreneurships have already been started in some parts of the southern India. Adoption of micro-climate environment in line with poultry enterprises will open up the scope for incorporating exotic sheep germplasm like Suffolk, Dorset, Awassi, fat-tail or fat-rump type sheep etc and goat germplasm like Spanish, Boer, Anglo-Nubian, Shami, Saanen, etc. for maximizing meat and milk production.

Managing the Transition Phase in Sheep and Goat Farming:

Peri-partum/transition period is a hypercritical phase with respect to physiological and metabolic adaptions to cope with the growing nutritional demands of the fetus as well as the ensuing lactation immediately post-calving. During late pregnancy and early lactation, ewes and does face significant nutritional challenges due to additional requirements of energy, protein and micro-nutrients (ICAR, 2024). Feeding management during transition period regulates the milk yield, subsequent reproductive structure, overall well-being of the animal and consequently economic returns to small ruminant enterprises. While the milk yield peaks around 3-4 weeks post-partum, the dry matter intake starts increasing gradually and peaks around 6–8 weeks post-partum, and thus creating a 2-4 week stretch of negative energy balance. The transition period is extremely delicate for all ruminants, including sheep and goats. In these species, the transition starts 2-3 weeks before and lasts 2-3 weeks after calving. Some of the drastic physiological changes during this period are outlined here.

- There are higher nutrients requirements for the last part of the pregnancy;
- Multiple births ask for additional requirements;
- Lambing/kidding is a stressful even;
- A reduction in feed intake and an appetite fluctuation;
- Mammary gland prepares itself for lactation;
- There is a general hormonal change;

All these events are generally prioritized to provide nutrition and survival during pregnancy and follow-up nutrition to offsprings through lactation. Thus, the additional energy, protein and micronutrient requirements needs to be available in a time-tested schedule so that sheep and goats shouldn't experience a negative energy balance (NEBAL) worsen by the fact that multiple births are very frequent in these species. The body mobilizes the endogenous lipid sources to produce more energy but the hepatic metabolism is unable to meet the high requirements of the transition period. Thus, there is a high risk of clinical or sub-clinical signs of "pregnancy toxemia". The animal management during this period must take into account their physiological and metabolic condition aimed at reducing the NEBAL through balancing the diet based on the real animal requirements, avoiding a strong energy deficiency for animals with higher genetic merit and preventing an excessive weight increase for the animal with only one fetus. It is often advised to supplement all the transition diet with methyl donors and vitamins of the B-group to sustain hepatic lipid metabolism, production, and milk quality up to lactation peak (NRC, 2007; Kour et al., 2024). Grouping animals by body condition and pregnancy stage, along with tailored rations and modern feeding practices, can help meet their high energy needs efficiently.

Flushing Ration:

About 2-3 weeks before the breeding season, "flushing" ewes/does by increasing their nutrition can promote body weight, bring them into heat earlier, and improve lambing rate.

Concentrate Supplements:

Supplementing grazing with a balanced concentrate mixture (e.g., maize, groundnut cake, wheat bran, de-oiled rice bran, molasses, minerals, salt) can be particularly helpful for lactating sheep/goats and breeding rams/bucks, especially in areas with limited pasture availability.

More Lambs per Lamb and More Kids per Kid:

In most parts of India, lambs are sold at the age of 2.5 to 3.5 months of age. The reasons are more of socio-economic compulsion rather than any scientific or economic merit. The farmer is of the view that he has no bearing on lamb’s preweaning growth so long milk is available from its dam. Because, native breeds of ewes except a few are poor milcher and their lactation hardly continues beyond 3-4 months, rearing lambs in the post-weaning period (3-6 months of age) involves accountable input cost. Moreover, small ruminant rearing is generally at the hands of rural poor and they have hardly any surplus money at hand to invest for a probable future return. In the hindsight, many farm and field evaluation trials have come up with a feeding schedule to harness a promising cost: benefit ratio of 1:2 to 1:2.5 during the post-weaning period (Sahoo et al., 2015; 2019a,b). This not only enable the farmer to manifold the income but also saves a young one from early slaughter thereby doubling the meat output from the same lamb that would have yielded half of the carcass weight at pre-weaning compared to that at post-weaning. This will ultimately reduce the burden of accelerated slaughter percentage, a direct threat to existence of small ruminant population and dependent livelihood.

Broiler Lamb/Kid Production:

Keeping in view that sheep and goats are mostly reared extensively, it will be interesting to know how they perform in a feedlot situation; i.e., to study the growth, carcass and meat quality of feedlot animals and to quantify the optimum time needed for them in a feedlot to achieve desirable growth and carcass quality. We need to provide lambs and kids with supplemental feed (creep feed) from a young age (1 month to 2-3 months) to ensure rapid growth and nutrient intake. An economic assessment on goat production in India revealed that opportunity cost of technological interventions on health care, nutrition and marketing together are equivalent to about 1.24% of total value of output (at current prices) from livestock sector in 2010-11 and 14.74% of the value of output from goat sector for the year 2012 (Dixit *et al.,* 2015). There is a need to determine suitable production systems using different breeds suited to the different environments which produce carcasses that cater to the needs for domestic and export markets and to study their performance in tropical and subtropical environments. Development of a carcass grading system and a suitable infrastructure in developing countries are some of the key requirements needed to establish a sustainable meat industry in parallel with commercial sheep and goat farming. With an increase in demand by consumers for low-fat red meat alternatives, the future of the small ruminant meat industry looks promising.

Broiler lamb/kid production can be targeted during pre- and post-weaning phase of life separately or consecutively. The advantage of additive approach involves maximizing pre-weaning weight gain through feeding of milk and/or milk replacer and additional creep feed for rapid adaptation to solid feed and early rumen development and then harnessing post-weaning marketing live weight, preferably at 5 or 6 months of age in high-gain kids/lambs. Farmers can adopt breed-specific feeding, i.e. tailoring feeding strategies to the specific needs of different sheep/goat breeds, considering factors like body weight gain, body condition score and genetically regulated early pre-weaning and post-weaning growth. Therefore, the farmer/entrepreneur can focus on following three principal objectives:

- Targeting optimization of input, i.e. improvement in FCR (achieving FCR 1:4 to 1:5 with economic input: output ratio of 1:2.8 to 1:3.2)
- Maintaining a dynamic finished population for sustained supply to the market
- Expanding marketing avenues and enhancing profitability and revenue through demand-driven pricing of the produce and products.

It is a fact that economics of feeding was the vital factor for feeding forage to ruminants because of the unique capability of these animals to convert non-edible fibre by virtue of rumen fermentation to digestible nutrients like microbial biomass and volatile fatty acids. Small ruminants are nothing different and therefore, a healthy rumen and rumen fill cannot be ignored, which ultimately provides protein and energy to the animals, and is the bottom line in any differential approach targeted at commercial rearing.

Quality Output:

The small ruminant production will be profitable if it is looked from an industry perspective that can provide job alternative to rural youth besides meeting the quantitative and qualitative demand of meat in the name of species having a ‘Designer Tag’ with desired functional properties benefit to human health and improving keeping quality (Sahoo et al., 2019b). the feeding strategy should be directed at exploring the potential of dietary polyphenols to influence milk fatty acid profiles and reduce the activity of rumen microbes involved in PUFA biohydrogenation. On similar line, incorporating herbage rich in PUFA can improve the meat/milk composition and nutrient content. Research and development strategies should focus on pros and cons of the following stall-feeding practices and to enumerate both quantitative and qualitative gain for profitable marketing of animal produce.

- High concentrate feeding
- Total mixed ration (TMR)
- Complete feed block/pellet
- Production of mixed silage and feeding
- Feed additives and supplements: inorganic and organic additives, phytochemicals, pre and probiotics, nutraceuticals, mineral and vitamin supplements

Feeding through Breeding/Reproduction:

An annual feeding plan is necessary to meet the nutrient requirement of these small ruminants in different physiological stages, viz. growth, puberty, pregnancy, lactation and transition (ICAR, 2024). The lambs/kids raised for breeding purposes needs to be fed economically to attain the desirable body weight at breeding or pubertal age. For example, a lambs/kids with birth weight say 3.0 kg can attain 15.0 kg at the end of preweaning age (3 months) and thus, they have 7 to 9 months period to attain another 15.0 kg to reach mature or pubertal body weight of 30.0 kg at 10 months or 1 year of age. It means the growth pattern during the first 3 months of life can be calculated at average daily gain (ADG) of 130-140 g/d, and then the lambs/kids can be reared economically in the later period with a lower input cost to sustain ADG at 70-80 g/d (3-10 months) or 50-60 g/d (3-12 months).

Pasture Lambing/Kidding:

This is another concept, in which farmers can coincide lambing with flush pasture availability/growth so as to sustain lactation and pre-weaned lamb nutrition. The grazing of sheep/goat can be timed to enhance regeneration of vegetation important for shade, habitat, and erosion control and rotational grazing should be adopted to avoid overgrazing and also, to facilitate worm-control programme.

Alternate Feed Resources:

Round-the-year nutritional security checks any decline in production during environmental and production stress in animals. This requires to expand feed resource base by utilizing crop residues, silage, grasses, hay, browse, plant leaves, shrubs, agro-industrial by-products, poultry litter, and other readily available alternatives. These can be cost-effective and improve animal productivity while reducing environmental impact. Additionally, these alternative feeds possess antioxidant, antimicrobial, and antiseptic properties that can enhance the quality of the meat and milk produced (Boudalia et al., 2024). By impacting the bacteria involved in ruminal biohydrogenation, alternative feeds can reduce methane emissions and contribute to a decrease in the carbon footprint. Overall, the use of alternative feed sources for small ruminants generally improves their apparent nutrient digestibility and productivity, and has an impact on the production of greenhouse gases, especially methane. There is a need to focus on forage quality, particle size, and appropriate supplements to maximize feed intake and utilization. There is a need to focus on promotion of supplementary feed preparation using region-specific and locally available inputs or resources so that farmers can prepare the feeds on their own with low investment.

Whole Farm Output Model:

This model is aimed at i) reducing age at puberty/sexual maturity/conception, ii) increasing rate of conception, iii) increasing litter size, iv) reducing number of empty days, v) increasing productive year and per animal reproductive efficiency will certainly help in attaining 'more sheep per sheep' and/or 'more goats per goat' thereby increasing input: output ratio and profitability. Automation in feeding and rearing practices with microchip-based disease diagnostics will aid in whole farm nutrient and health management system. A theoretical calculation is depicted here for better understanding of the concept.

AI in Small Ruminant Farming:

In today's digital age, utilizing computer models and nutritional systems can be applied to predict feed intake, nutrient requirements, and methane production in small ruminants. Further improvements in the nutritional efficiency of sheep and goats can be obtained with the integration of mechanistic nutrition models and the data derived from sensor technology, especially those that allow monitoring of the movement and environmental effects on grazing and browsing sheep and goats (Cannas et al., 2019). Application of AI has already begun to revolutionize traditional farming practices, and its impact on livestock management is poised to be equally transformative, and we can delve deeper into the complexities of livestock management, making informed decisions that enhance productivity, sustainability, and animal welfare (Rebez et al., 2024). Similarly, precision Livestock Farming (PLF) applies a complex of sensor technology, algorithms, and multiple tools for individual, real-time livestock monitoring (Paolino et el., 2025). But introduction of PLF technologies in extensive livestock farming can provide real-time results on the conditions of grazing animals and their interaction with climate change. Greenhouse gas emissions and water shortages can be addressed by applying PLF to detect temperature, type of feeding and water consumption. Large data sets made available by sensory technology can be interpreted with artificial intelligence tools and machine learning techniques. The predictive analytical models embedded with machine learning has helped better decision-making and enabled farmers to remotely monitor livestock health by wearable devices that keep track of animal vital signs and behaviour (Arshad et al., 2024). The veterinarians can employ advanced AI-based diagnostics for efficient parasite detection and control. Various contemporary techniques like sky-shepherding, virtual fencing, advanced parasite detection, automated counting and behaviour tracking, anomaly detection, precision nutrition, breeding support, and several mobile-based management applications are appeared to be promising. The concept of RFI-based selection, real-time intervention in health management, strategic feeding and nutritional manipulation to immune the animals against production decline, intelligent body scoring system can be implemented in profitable small ruminant production. Similarly, application of AI in meat production system will help meat-based companies to increase their revenue by speeding up the production process, reducing maintenance time and hence the production downtime, decreasing the chances of failure by automating almost every process and eventually delivering an excellent customer experience by predicting their likes, dislikes, and desires. Production of clean, hygienic and wholesome meat for consumers, and also for export market will definitely increase the revenue in entrepreneurship.

Intensive Feeding – Small Ruminant Entrepreneurship:

- Feeding of milk replacers/liquid milk formula (LMF)
- Adoption to solid feed (Creep mixture)
- Spare of ewe/doe milk by allowing suckling after evening milking and replenishment vide milk replacer
- Weaning at 10 wk + LMF (up to 3 m)
- Shift to finishing diet
- Marketing at 4.5-5 months (depending on breed & body size and consumer preference
- Sale of meat and spared milk
- Strategic marketing for quality meat
- Preparation & sale of meat products for more profit (e.g. Nuggets)

For maximizing production output in commercial sheep/goat farming or entrepreneurship, Shaoo (2019c) emphasized to focus on 1) feeding of pre-weaning stock; 2) feeding of post-weaning stock; 3) developing feeder kids or lambs; 4) market-driven feeder lamb/kid production; 5) feeding of male and female lambs/kids for early sexual maturity with desired weight; 6) feeding of breeding stock; 7) feeding during gestation and lactation and 8) economizing the feeding protocol. Revisiting commercial small ruminant production is thus focussed at augmenting sheep and goat production and products by increasing whole farm productivity through adoption of the following innovative and promising technologies.

- Introgressing of prolific gene in non-prolific sheep to increase twins/triplets;

- Genetic improvement of native sheep by adopting inter-se-mating with heavier mutton breeds;
- Accelerated lambing to achieve 3 lamb crops in 2 years or 9 lamb crops in its production life as against 6 lambs;
- Maximization of pre- and post-weaning weight gain with higher feed efficiency;
- Enhancing quality meat and meat products and their strategic marketing;
- Widening the scope of sheep/goat rearing by establishing it as a '5-STAR' animal.

The inflow of commerce in to this livestock industry will definitely open up establishment of small to large scale sheep and/or goat units at village or panchayat level thereby creating job opportunity to rural youth. Further, there is scope of collateral expansion aimed at strategic rearing and marketing practice through i) harnessing quality and consumer trait-specific meat and value addition with technological manipulation for manufacturing ready-to-eat meat products; ii) improving the current status of meat production, handling and marketing; iii) developing technologies for value addition to meat by processing into meat products; iv) providing research and development and marketing support to the export meat trade; v) launching human resource development programmes in teaching, research, training and extension activities of meat science and technology.

Conclusion:

The importance of developing sustainable small ruminant production through a conceptual framework that allows the integration of sound management practices based on the 3 Ps (Profits, People and the Planet) is considered a prudent path for the future. Societal development through productivity augmentation in migratory and sedentary flocks cannot be ignored, which accounts for a major small ruminant population in our country. Considering the wide prevalence of the mixed farming system and absence of high input landless farming system of livestock rearing in India, a strategy to augment the small ruminant production cannot be seen in isolation, but only as a component of a farming system approach where the household livelihood as well as food and nutritional security concerns are addressed. Further, confronted with environmental constraints and food insecurity driven by demographic growth, there is an imperative need to cultivate more sustainable animal production practices. In small ruminants such as sheep and goats, the utilization of alternative feeds, such as shrubs, plants, and agro-industrial by-products, can significantly enhance animal productivity, reduce carbon footprints, and mitigate greenhouse gas fluxes. Application of AI can help identify the most suitable systems for managing grazing sheep and goats and contribute to selecting more sustainable and efficient solutions for optimizing production.

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Chapter-5

Current Scenario, Constraints, and Strategies to Overcome the Requirement of Feed and Fodder in India

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Introduction:

Since ancient times in India, Livestock rearing has been an integral component of the agriculture sector in rural India. The Livestock in India also serves as a risk mitigation strategy for small and marginal farmers, thus it can be considered insurance against crop failure. According to the 20th livestock census, the livestock population of India expanded from 512.06 million in 2012 to 535.82 million in 2019 (DADH, GOI). India is the world's largest milk producer (239.30 million tonnes), and the milk production has increased by 3.78% over the previous year. In India, milk production has increased by 51.05% over the past 10 years from 146.31 million tonnes during 2014-15 to 239.30 million tonnes during 2023-24, but faces persistent challenges in meeting its vast animal population's feed and fodder requirements. The country's livestock sector is growing, yet the quality feed and fodder supply has not kept pace, leading to regional deficits and impacting productivity. The sustainability of livestock cannot be achieved without addressing the challenges of feed and fodder development in the country. India's feed and fodder sector faces significant challenges in meeting the nutritional needs of its livestock, which supports the livelihoods of millions and contributes 4% to the national GDP.

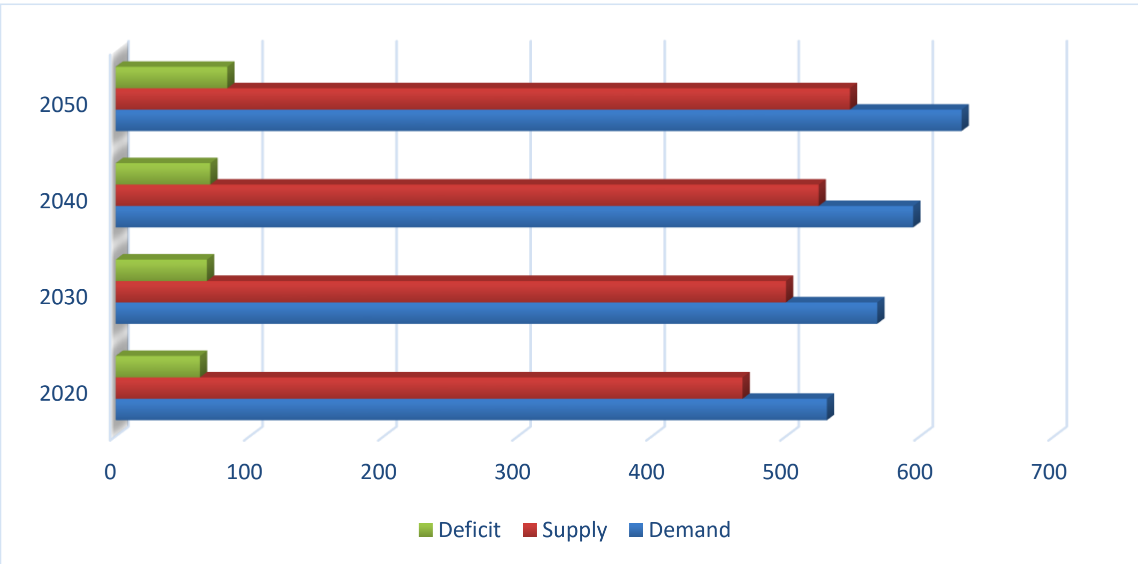
In the current scenario, India is experiencing a significant animal feed and fodder shortage due to a persistent and significant gap between the demand and supply of animal feed and fodder. According to the estimates of Vision 2050 published by the Indian Grassland and Forage Research Institute, Jhansi, the demand for dry fodder was 530.5 MT in 2020 which is expected to reach 568.1 MT in 2030 and 594.9 MT in 2040. Whereas, the availability of dry fodder was 467.6 MT in 2020 and is projected to be 500 MT in 2030, and 524.4 MT in 2040. In case of green forage, the demand and supply were 851.3 MT and 590.4 MT, respectively in 2020. In the year 2030, the estimates of demand for green forage are expected to be 911.6 MT against the availability of 687.4 MT, and in 2040, the demand and supply of green forage will reach up to 954.8 MT and 761.7 MT, respectively. The projected demand for green and dry feed by 2050 is 1012.7 and 631.0 million tons, respectively, against the supply of 826.0 MT and 547.7 MT, resulting in a deficit of 18.4% in green fodder and 13.2% in dry fodder. The IGFRI Vision 2050 reported a deficit of 44% in the case of concentrate feeds.

The persistent shortage of animal feed and fodder in India arises from several interrelated factors, including limited land allocation, the reduction of land resources due to urbanization, and climate change. Only about 4% of India's gross cropped area is designated for fodder cultivation, as most arable land is prioritized for food crops to meet the needs of the growing human population. Fodder production heavily depends on the monsoon, leading to significant shortages during dry seasons. The increasing livestock population, particularly improved breeds with higher nutritional demands, has outpaced the growth in fodder supply. This rising demand for feed and fodder is expected to continue increasing in the coming years. Despite these challenges, there is a need to explore options to bridge the demand-supply gap and enhance fodder availability.

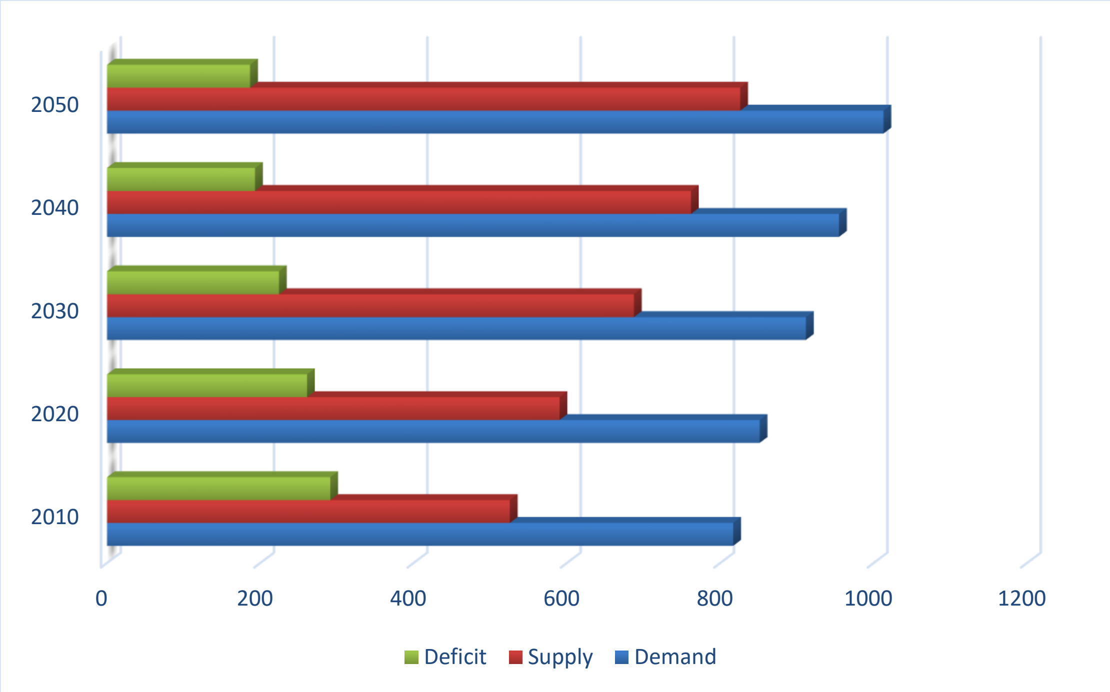
Table: Estimates of Demand and Supply of Dry and Green Forages (MT)

Year	Demand		Supply		Deficit		Deficit as %	
	Dry	Green	Dry	Green	Dry	Green	Dry	Green
2020	530.5	851.3	467.6	590.4	62.85	260.9	11.85	30.65
2030	568.1	911.6	500.0	687.4	68.07	224.2	11.98	24.59
2040	594.9	954.8	524.4	761.7	70.57	193.0	11.86	20.22
2050	631.0	1012.7	547.7	826.0	83.27	186.6	13.20	18.43

Source: IGFRI Vision 2050



Estimates of demand, supply, and deficit of dry fodder



Estimates of demand, supply, and deficit of green fodder

Factors Affecting Feed and Fodder Scenario:

Resource Constraints: There is a scarcity of available land and water for fodder production in the country. Only 4.9–5.23% of agricultural land is dedicated to fodder cultivation, with priority given to food crops like grains and pulses. Also, there are limited irrigation facilities for fodder crops, especially in rain-fed regions.

Climate Variability: Drought and erratic rainfall severely impact fodder availability, especially in arid and semi-arid zones. 70% of fodder production occurs during the Kharif season, causing shortages in dry months. Increased droughts and extreme weather reduce fodder availability, necessitating drought-resistant varieties

Low Productivity: Traditional varieties and poor management practices limit fodder yield per hectare. Traditional farming methods result in green fodder yields 3–4 times lower than global averages. Over 60% of available fodder lacks adequate nutritional value, affecting livestock productivity.

Crop Residues: Increasing mechanization and alternative uses (biofuel, packaging) reduce the availability of crop residues for livestock.

Demand-Supply Dynamics: Rising livestock population is a major challenge for the demand and supply dynamics of feed and fodder in India. Livestock numbers grew 1.5 times in 25 years, while fodder cultivation area remained stagnant. Regional disparities in fodder cultivation are also highly responsible for affecting the demand of feed and fodders. States like Rajasthan, Uttar Pradesh, and Gujarat are having surplus amount of fodder, while states including West Bengal, Kerala, Jharkhand, and Uttarakhand face 35–67% green fodder shortages.

Socioeconomic Factors: 80% of livestock owners are small/marginal farmers with limited resources to adopt advanced practices. Over 60% of livestock depend on degraded common pastures, exacerbating land degradation.

Major Constraints in Fodder Production and Management in India:

- **Uncontrolled Grazing and Poor Management Practices:** Due to over-grazing, the productivity of the pastures has been declining over the years, and the trend could well continue in the future. Weak fodder base due to problems in pasture management and shrinking of common properties makes this problem doubly serious.
- **Regional Imbalance in Feed and Fodder Availability:** One more threat is the regional imbalance in fodder availability. There are regional and seasonal disparities in fodder production and availability. Due to a lack of sufficient post-harvest and storage facilities, surplus fodder is not properly utilized.
- **Low Productivity of Available Land:** The productivity of land available for fodder production is low due to the non-availability of required resources and the non-adoption of innovative production technologies. Water scarcity limits irrigation, particularly in rain-fed regions. Fodder production is monsoon-dependent, causing lean-season shortages. Only 10-15% of farmers use preservation techniques like silage. Due to outdated seeds and cultivation methods, traditional practices yield 40-50% less than the potential output.
- **Lack of Awareness about Feed and Fodder Production and Management:** Despite the importance and contribution of forage production in the livestock sector, the area has not been given attention. Farmers and extension workers are not aware of fodder production, utilization, and marketing aspects.

Strategies to Combat Increasing Fodder Demand:

Meeting India's rising fodder demand requires a combination of improved crop varieties, innovative production technologies (such as hydroponics), better storage, efficient use of by-products, and robust policy support. Integrated approaches that combine these strategies with strong research, extension, and farmer engagement are essential for sustainable livestock productivity and nutritional security. These strategies can be described as follows.

- **Enhance Fodder Productivity:** In the current scenario, the area under fodder crops is limited, and it cannot be increased; thus, there is a need to adopt a multi-pronged strategy for adequate availability of fodder during different climatic conditions. To increase the productivity of available land, proper planning and optimum utilization of resources such as fertilizers, seeds, water, etc, are required. This can be achieved by the adoption of high-yield, drought-resistant fodder varieties and improved agronomic practices.

- **Adoption of High-Yielding and Climate-Resilient Varieties:** Increasing fodder demand can be addressed by disseminating improved fodder crop varieties such as Hybrid Napier, COFS-29, and multi-cut oats to boost yields and resilience to climate variability. There is a need to encourage drought-tolerant and biofortified fodder varieties for regions facing water scarcity and poor soils.
- **Improved Storage and Preservation Techniques:** Fodder supply can be improved by promoting silage and hay-making techniques to ensure fodder availability during lean periods and reduce post-harvest losses. Establishment of fodder banks at village or block levels to buffer against seasonal shortages can be used as an effective tool against seasonal variability.
- **Utilization of Crop Residues and By-Products:** Encouraging the use of crop residues like straw, stover, sugarcane tops, and their treatment, such as urea treatment, helps to enhance nutritional value and digestibility. By promoting the use of oilseed cakes and agro-industrial by-products as supplementary feeds, the demand of concentrate feeds can be minimized up to a certain extent.
- **Diversify Fodder Sources:** Green fodder supply can be improved by increasing area under cultivated fodder crops, increasing productivity of existing cultivated fodder crops through adoption of improved and innovative cultivation technologies, by inclusion of fodder crops in cropping systems on rotational basis, fodder production from marginal land, hydroponic fodder production, exploring alternative sources of fodder like azolla, and overcoming the dry fodder shortage by Azolla. Alternate land use systems like Silvipasture /hortipasture are being practiced in big scale as it integrates the concerns for productivity, conservation of resources and environment, and profitability. This system aims at optimizing land productivity, conserving plants, soils, and nutrients, and producing forage, timber, fruit, and firewood on a sustainable basis (Roy *et al.* 2019). Incorporating fodder crops into crop rotations, intercropping, and mixed cropping systems helps to maximize land use and improve soil fertility, and also promotes agroforestry and crop-livestock integration for year-round fodder availability.
- **Hydroponic Systems:** Hydroponics is the technique of growing plants using a water-based nutrient solution rather than soil, in an environmentally controlled house or machine. Hydroponics is an innovative method for cultivating fodder, offering several advantages over traditional methods. This soilless technique involves growing plants in

a controlled environment, typically a greenhouse or polyhouse, using a water- or nutrient-rich solution. Hydroponic fodder production addresses various challenges associated with conventional cultivation, providing a sustainable and efficient alternative. Seeds are germinated and grown in trays using a water- or nutrient-rich solution for about 6-8 days. Various cereals (barley, oat, wheat, sorghum, maize) and legumes (alfalfa, cowpea) are successfully cultivated. Green fodder is ready for consumption in a short period, typically around 7 days. Controlled Environment hydroponic fodder production is gaining attention for its water-saving benefits. The cost of seeds constitutes a significant portion of the overall expense in hydroponic fodder production, accounting for around 90%. Despite higher seed costs, the benefits of enhanced palatability, digestibility, and nutrition make hydroponic fodder an attractive option. Hydroponic fodder is considered more palatable, digestible, and nutritious compared to traditionally grown fodder. Animals fed with hydroponic fodder may experience additional health benefits. Hydroponically grown crops exhibit faster growth—up to 50% faster—and yield higher quantities of better-quality fodder. This method of fodder production is considered eco-friendly and helps alleviate pressure on land, cope with water scarcity, and mitigate the impact of irregular rainfall and frequent droughts on traditional fodder crops. Hydroponics is being increasingly adopted in many countries to produce green fodder for cattle, poultry, and other livestock in response to agricultural challenges.

- **Integrated farming:** An integrated farming system is a sustainable agricultural approach that combines livestock, crop production, fish, poultry, tree crops, plantation crops, and other systems that mutually benefit each other. It helps increase productivity per unit area by intensifying crops and related enterprises. It improves soil fertility and texture through effective crop rotation and the use of organic compost. Additionally, it minimizes nutrient losses and reduces the production costs of components by recycling inputs from the by-products of related enterprises.
- **Silvipasture:** Silvipasture is the practice of integrating trees, forage, and the grazing of domesticated animals on the same land in a mutually beneficial way. Well-managed silvipasture systems can produce as much forage as open-pasture systems under favorable conditions. Silvipasture systems have also been observed to yield forage of higher nutritional quality than non-silvipasture forage under certain circumstances. Increased forage availability has been noted in silvipasture systems compared to open-pasture systems during drought conditions.
- **Hortipasture:** Hortipasture involves growing various perennial grass species alongside

fruit trees. In the hortipastoral system, the spaces between fruit tree species are utilized for cultivating grasses and grass-legume mixtures. Livestock are allowed to graze on the available pasture for 3-4 months each year, but only during the dormant season of the fruit trees. Intercropping various leguminous grasses with fruit trees enhances soil fertility through nitrogen fixation. Hortipasture systems hold significant potential to mitigate climate change by sequestering carbon while providing fodder and fruit supply, particularly in semi-arid regions.

Government and Technological Interventions:

The Department of Animal Husbandry, Dairying and Fisheries, Government of India, has been implementing the Centrally Sponsored National Livestock Mission with a Sub-Mission on Feed and Fodder Development since 2014-15. The National Livestock Mission subsidizes fodder seed production and silage units. The Rastriya Krishi Vikas Yojana (RKVY) promotes fodder entrepreneurship.

Conclusion:

The steadily developing livestock sector in India contributes to stable domestic demand for animal feed. While India faces significant challenges in meeting its animal feed and fodder needs due to land constraints, climate change, and management issues, there is considerable scope for improvement through targeted policy support, technological innovations, and sustainable resource management.

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Chapter-6

Nutrigenomics Approaches to Improve Animal Production

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Introduction:

In livestock farming, nutrition along with genetics and management are important factors involved in achieving maximum production. Globally, the livestock sector has witnessed a tremendous increase in the production potential of various food-producing animal species through employment of genetic and breeding improvement strategies. Increases in the productive potential of the animals necessitates need to identify key molecular mechanisms underlying several biological processes that govern production and health of animals in response to external factors like nutrition. Our understanding of animal nutrition has changed significantly because of the interdisciplinary study of nutrigenomics, which stands at the intersection of genomics and nutrition. In the recent past, technological advancements in the scientific fields and research have made it possible to understand nutrient-gene interactions and their effects in biological systems through various 'Omics' technology. Omics refers to the collective technologies used to explore the roles, relationships, and actions of various types of molecules that make up the cells of an organism. Major "Omics" technologies pertinent here are genomics, transcriptomics, proteomics, metabolomics, and metagenomics. A comparatively newer "Omics" technology is Nutrigenomics.

Nutrigenomics is the study of the genome-wide influences of nutrition or dietary components on the transcriptome, proteome, and metabolome, of cells, tissues or organisms, at a given time (Muller and Kersten, 2003). Nutrigenomics is fundamentally an approach of applying high throughput genomics tools in nutrition research. The information flow in biological system includes transfer of information from DNA to RNA and from RNA to proteins. Briefly it can be said that DNA makes RNA and RNA makes proteins, the expression of which brings functional outcomes in the body.

With potential applications in modifying animal features like muscle growth and fat storage, nutrigenomics affects epigenetic changes and gene expression patterns (Bordoni and Gabbianelli, 2019; Ding *et al.*, 2022). The rapidly developing field of nutrigenomics highlights the crucial role it plays at the interface of human and animal well-being, offering a viable path forward for effective and sustainable animal nutrition practices. Nutrigenomics in animal nutrition offers great potential for novel developments in the future. Estimates suggest that cutting-edge technologies, including big data analytics, precision feeding systems, and advanced genomics, will continue to be integrated to improve our knowledge of gene-nutrient interactions and customise nutritional plans (Asmelash *et al.,* 2018; Hassan *et al*., 2022).

Nutrient Regulation of Gene Expression:

The mechanism of nutrient mediated changes in gene expression are summarized briefly in following sections.

1. Transcription Factor Mediated Activity:

Transcription factor (TF) is a protein that controls the rate of transcription i.e. gene expression by promoting or suppressing transcription. Few transcription factors require external signal for their activation. These signals may be some ligands. Peroxisome proliferator-activated receptors (PPARs) are ligand-activated TF and fatty acids or their derivatives as a ligand bind with PPAR. In the nucleus PPAR binds with regulatory region of DNA near the gene under their control and influence expression of genes involved in fat and carbohydrate metabolism. Other ligands include micronutrient like vitamin A or D, sterols and other dietary compounds like flavonoids. These ligand-activated TF bind with response element and activate gene transcription. There are also certain non-ligand-dependent transcription factors.

2. Transcription Factor Acetylation:

Acetylation describes a reaction that introduces an acetyl functional group into a compound. Acetyl-CoA as the acetyl group donor is involved in histone acetylation on lysine residue. Histones around which DNA is wind enables necessary compaction to fit the large genome of eukaryotes inside cell nuclei. Histone acetylation, one of the post-translational modifications is an epigenetic phenomenon that regulates gene expression. It is reported that on feeding (compared against fasting) a diet, upstream transcription factor-1 is acetylated and activated, thus allowing recruitment of accessory factors that increase expression of fatty acid synthase (a central enzyme in lipogenesis) gene (Wong *et al.,* 2009).

3. Nutrient Transport-influenced Transcription Factors:

Homeostatically-influenced transport of nutrients control cell function through provision of needed substrates (Cousins *et al.,* 2010). Nutrient transport has physiological consequences. For example, zinc could act as second messenger (intracellular signaling molecules released by the cell in response to exposure to extracellular signaling molecules) and transport of zinc is linked with cell signaling. Zinc transporters proteins (ZIP; responsible for zinc influx into the cell) are associated through transcription factor CREB (cAMP response element-binding protein that regulate transcription of gene) with the activation of the interferon-γ gene that have potentiating effect on T cell activation (Aydemir *et al.*, 2009).

4. Nutrient-influenced Gene Repression via Response Element Placement:

Placement of the response element i.e. RE (short sequences of DNA within a gene promoter region that are able to bind specific transcription factors and regulate transcription of genes) within the non-coding region can dictate whether a nutrient-binding transcription factor acts as an activator or a repressor of transcription. For example, metal regulatory transcription factor-1 (MTF-1) is responsive to cellular zinc status. MTF-1 acts as repressor of ZIP-10 gene (that control influx of zinc into the cytoplasm) under conditions of normal zinc status and activator for ZnT-1 gene (which control efflux of zinc from cell to outside). Under zinc restriction conditions MTF-1 repress ZIP-10 gene due to presence of metal response element on that gene which prevent RNA polymerase-II (enzyme that catalyses the transcription of DNA to mRNA) movement necessary for elongation process involved in transcription.

Nutrigenomics Approach:

Two different approaches can be employed in nutrigenomic studies as mentioned below.

1. Candidate Gene Approach:

This approach involves studying nutrient driven alterations in a specific gene and protein expression. This approach deals with the study of how specific diet or nutrient affect phenotypic outcome through specific gene- and protein- expression, ultimately producing particular metabolite in the body. Thus, this approach leads to identification of nutrient-dependent regulatory pathways influencing homeostasis. Different technologies are used to detect and quantify the expression level of individual genes (e.g. Northern blot, SAGE or real-time PCR) and their products (e.g. Western blot and ELISA) in this approach. This candidate gene approach has allowed a thorough investigation of the mechanisms underlying certain metabolic functions in animals. For example, classic gene expression studies greatly contributed to the understanding of the etiology of fatty liver in dairy cows at calving (Gruffat *et al.,* 1997; Bernabucci *et al.,* 2004), increased capacity for gluconeogenesis in early lactation in cows (Greenfield *et al.* 2000), response of genes to nutritional or physiological status in the intestine (Shirazi-Beechey, 2004), adipose tissues (Bonnet *et al.,* 2000) and muscle (Hocquette *et al.,* 2001) of ruminants. Using this approach, the influence of breed or genetic polymorphism on gene expression have also been studied by various workers. A candidate gene study involving quantitative trait locus (QTL; section of DNA i.e. locus that correlates with the variation of quantitative trait) for muscle development found mutations of myostatin (that inhibit myogenesis) gene expression leading to translation inhibition of myostatin which was responsible for higher muscle growth in sheep (Clop *et al.* 2006); similarly the inactivation of the myostatin signal during development was found responsible for hyper muscularity in cattle (Grobet *et al.* 1997).

2. Systems Biology Approach:

Systems biology deals with the study of whole biological systems (cells, tissues, and organisms) using holistic methods. This approach involves identifying and cataloguing a molecular biomarker in the form of a gene, protein or a metabolite. This approach leads to identification of a molecular signature associated with specific diet or a particular nutrient. For example, presence or absence of biomarker of early dysregulation or susceptibility to metabolic disease which ultimately help in devising nutritional strategies accordingly. This is also called as genomic approach. Transcriptomic, proteomic and metabolomics are the important tools involved in this nutrigenomic approach. Outcomes of systems biology could be an accurate supply of nutrients for meat or milk production or an optimisation of husbandry practices in livestock species. Another outcome of genomics is the development of diagnostic tests based on biotechnological tools, which may be useful for the livestock industry for detection of animals with desirable traits (Cassar-Malek *et al*., 2008).

Applications of Nutrigenomics:

Diary Animal Nutrition:

Nutrients regulate mammary fatty acid synthesis at the transcriptional level. Here PPAR transcription factor and their target genes play a major role. In dairy animals PPARα control lipid metabolism and inflammation in liver, PPARβ/δ control glucose uptake in mammary tissue, and the PPARγ control milk fat synthesis and mastitis (Bionaz *et al.,* 2015). PPAR in general are activated by fatty acids and hence dietary supply of these particular fatty acid (saturated long chain fatty acids particularly palmitate and stearate for PPARα/γ in dairy cows and polyunsaturated fatty acids in monogastrics) are very important.

Liver X receptor-α (LXRα) controls the expression of SREBF1 in bovine and goat mammary epithelial cells (reviewed by Bionaz *et al.,* 2015). The LXRα also can control the expression of lipogenic genes in a SREBP1-independent manner and can increase lipogenesis in mammary cells. As LXRα play important roles in metabolism, infection and immunity and activation of LXRα could inhibit LPS-induced mastitis, it may serve as a new target for mastitis treatment beside its role as regulator of milk fat synthesis. In this context, LXR holds potential for reducing use of antibiotics for treatment of mastitis (Hu *et al.,* 2019) and nutritional modulation of LXR expression holds scope in reducing drug (antibiotic) residue in milk and safe food production. Activation of PPARγ lowers somatic cell count in milk and have positive effect on liver and neutrophil response to inflammation (Richards *et* *al.,* 2014). However, this activation of PPARγ is tightly related to the simultaneous activation of RXR by vitamin A derived 9-cis-retinoic acid (Wang *et al.*, 2010), thus in-vivo supplementation of vitamin A for activation of LXR TF is important in the management of mastitis.

The Vitamin D receptor (VDR) is regulated by vitamin D and retinoic acid (Horst et al., 1994) and thus a nutrigenomic interplay between vitamin D and vitamin A may exists. Due to its role in calcium metabolism, VDR is crucial in dairy cows and especially in early postpartum period when the incidence of milk fever is greatest. VDR also can be activated by ω6 and ω3 PUFA (Haussler *et al.,* 2008), hence, a potential exists for improving milk fever in dairy cows through nutrigenomic intervention using LCFA (Bionaz *et al.,* 2015). Sterol Regulatory Element-Binding Transcription Factor/Protein 1 (SREBP-1) is a key positive regulator of milk fat synthesis (Li et al., 2014). The study with feeding long chain fatty acid (LCFA) in dairy cows revealed an inverse relationship between t10, c12 CLA and de novo fatty acid synthesis due to a decrease in SREBF1 dependent expression of fatty acid synthase (FASN), acetyl-CoA carboxylase α (ACACA), and stearoyl-coenzyme A desaturase (SCD) (Peterson et al., 2004). Similarly, conjugated linoleic acid (t10, c12) and a milk fat–depressing diet (i.e., high energy and low forage plus high oil) significantly reduced the bovine mammary tissue expression of SREBF1 and consecutively decreased fatty acid synthase (FASN), lipoprotein lipase (LPL), and insulin induced gene 1(INSIG1) expression (Bauman, 2006).

Non-ruminant Nutrition:

In pigs, nutrigenomic studies have mostly focused on the expression of genes involved in the functioning of the liver, adipose, intestine, and muscle tissues (Loor et al. 2015). It was observed that soy-based diet altered the expression of genes involved in oxidative stress response in the liver (Schwerin *et al*., 2002). In piglets exposed to lipopolysaccharide feeding of a soybean protein (fermented soybeans) was found to influence transcriptional profile of 40 genes in leukocytes which were involved in reducing the inflammatory response (Roh *et al*., 2015). Several studies with various fat sources have been undertaken in pigs targeting genes involved in adipogenesis, lipogenesis, and lipolysis in the adipose tissue. Recently, Benítez *et al.* (2019) carried out global transcriptomic analysis of pig subcutaneous adipose tissue and showed that breed specific differences due to structural variants located near promoter of genes that are sensitive to nutrients can modulate gene expression.

In poultry species Rebel *et al.* (2006) studied the effect of supplementing hens' diet with vitamins and minerals on the intestinal transcriptional profile of the offspring. They found that mineral and vitamin supplementation increased the mRNA level of genes associated with turnover and proliferation of intestinal cells. In this experiment genes studied were those involved in epithelial turnover and maturation (cognin/prolyl-4-hydroxylase/protein disulfide isomerase, CRPductin-alpha, cytochrome p450 A37, ADA and Fc fragment of IgG binding protein) and genes involved in metabolic regulation (CDH-1, fatty acid binding protein 6; protein disulfide isomerase A6 precursor and GOB-4).

Nutritional Epigenetics:

Epigenetics refers specifically to the mechanisms for silencing or activating gene expression independent of the gene's DNA sequence. Nutrition is an important environmental stimulus that brings about epigenetic changes which have applications in altering progeny performances and productivity improvements in livestock species. Nutrition has profound effects on the growth and performance of any individual right from the beginning stages of its life before it is born. This developmental programming encompasses perturbations during critical window of prenatal or postnatal stages that have long-lasting effects on performance of the individual. This concept can be applied in livestock species for altering the bio-physiological expression in the offspring in their postnatal life targeting economically important production traits and certain health attributes. This is specifically more applicable in pig and poultry industry where reproductive cycles are rapid and large number of offspring are produced.

Challenges in Nutrigenomics Research:

Although promising, nutrigenomics research has several issues that need to be carefully considered. In general, the sensitive nature of genetic data and the possibility of unpredictable consequences regarding genetic discrimination, consent, and privacy give rise to ethical considerations (Ceriani *et al.,* 2023). Additionally, because gene-nutrient interactions are complicated and health impacts are multilevel, evaluating data from nutrigenomics studies presents significant challenges. Robust analytical frameworks and standardized procedures are necessary to reliably draw results on the complexities of diet-induced regulation of gene expression (Mierziak *et al.,* 2021). Large-scale, longitudinal studies that capture the dynamic character of gene-diet interactions across time are thus urgently required to draw firm and thorough connections. These kinds of investigations are necessary to find patterns, take individual variability into consideration, and verify results among other populations (Singh, 2023). To advance nutrigenomics and realise its full potential in creating individualized dietary recommendations, it is imperative that these issues be resolved.

Conclusion:

Nutrigenomics is the study of the genome-wide influences of nutrition or dietary components on the transcriptome, proteome, and metabolome of cells, tissues or organisms, at a given time. It is an innovative approach to study the nutrition precisely and completely. Nutrigenomic assessment is a powerful endpoint in ascertaining the exact requirement of nutrient for a specific function. Further, nutrigenomics has an important application in clinical nutrition for understanding the mechanism and developing strategies for prevention- and complementary therapy- of a particular disease condition. Also, nutrigenomics is essential for evolution of new genomics-based phenotypical biomarkers/molecular signatures needed for early detection of diseases and production parameters driven by diet or nutrition of animals. Nutrigenomics is an indispensable for validating the effectiveness of nutrients and dietary bioactive ingredients as functional food components or nutraceuticals. As it is a holistic approach of studying nutrition, there is a need of trans- and multi-disciplinary collaborative efforts for successful applications of nutrigenomics.

In summary, nutrigenomics has the potential to completely transform the field of animal nutrition research by providing a customized, precision-based strategy that enhances health and performance while simultaneously advancing efficient and sustainable farming methods. Continued research and cooperative efforts are necessary as we explore this field to fully realize its potential in influencing animal nutrition in the future.

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Chapter-7

Recent Insights on Micronutrients in Animal Feeding and Supplementation Strategies.

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Introduction:

Minerals are structural, regulatory and vital components of body affecting activities of numerous enzymes, hormones, as constituents of body fluids and tissues, and as regulators of cell replication and differentiation. After energy and protein, minerals are the major nutrients required and should be in the given priority in order to optimize reproduction in dairy cattle (Bindari, *et al.,* 2013). Minerals are required in reproductive process because of their role in maintenance, metabolism and growth. Beside energy and protein, deficiency of these elements such as calcium, phosphorus, iron, zinc and copper etc. in blood have been reported to be a predisposing factor for the occurrence of reproductive disorders in dairy animals (Sheetal *et al.*, 2014). As per their requirement, minerals are divided in to two categories i.e. macro minerals required in more than 100 ppm in diet and these are calcium, phosphorus, magnesium, potassium, sulfur, sodium and chloride. The second category is trace or micro minerals such as cobalt, copper, iodine, iron, manganese, selenium and zinc; and is required in less than 100 ppm diet of animals. Animals obtained minerals through the consumption of feeds, fodders, water and supplementation of inorganic salts in the ration. This paper is reviewed to highlight recent insights on micronutrients in animal feeding and supplementation strategies.

1. **Calcium (Ca**):

Ca plays a very importance role in structural and physiological functions activity of animals. Ratio of Ca: P between 1.5:1 and 2.5:1 for lactating cows caused no problems. Monogastric animal' diet must have at least 1:1 Ca: P ratio. Lactating cows must be provided with adequate amounts of Ca to maximize production and minimize health problems. Other function of Ca is to allow the muscle contraction. A reduction in muscle contractility affects rumen function; lower nutrient intake thus leads to negative energy balance. This results in increase in fat mobilization leading to fatty liver syndrome and ketosis. It has been shown that plasma calcium concentration of 5 mg/ml reduces abomasal motility by 70% and the strength of the contraction by 50%. Low calcium concentrations also prevent insulin production, further exacerbating this situation (Goff, 1999). Muscle tone in the uterus will also be adversely affected with cows experiencing prolonged calving and retained placenta.

Uterine involution may also be impaired giving rise to fertility problems. The major concern in feeding of dry cows is to provide adequate Ca and P to avoid occurrence of milk fever. Hypocalcemia in periparturient animals is major cause of decline in smooth muscle contraction, suppression of dry matter intake, increase in body fat mobilization in the form of non-esterified fatty acids (Martinez *et al*., 2014). Recent study has demonstrated dietary Ca concentration is not only risk factor for milk fever, the dietary cations, especially K, induce metabolic alkalosis in the prepartum dairy cow and thus reduces the ability of the cow to maintain Ca homeostasis (Goff and Horst, 1997). Milk fever also increases the incidence of many periparturient disorders such as dystocia, retained placenta, mastitis, displaced abomassum and ketosis. Hypocalcemia is also responsible for impaired immune function. It has been suggested that 48 h of parathyroid hormone stimulus is required to mobilize ca from skeleton (Goff *et al*., 1986) and this lag phase play important in the development of milk fever (DeGaris and Lean, 2008). NRC has recommended that Ca content be 0.65% of the total ration on DM basis for high producing cows.

2. Phosphorus (P):

It is the second most abundant mineral element in the body with 80 to 85% of P found in the bones and teeth. Phosphorus is involved in a number of metabolic activities and energy transfer reaction in the body. It is required for normal milk production, growth, and efficient use of feed and by the rumen microorganisms in the digestion of cellulose and synthesis of microbial protein. A deficiency of P leads to decline in fertility rate, feed intake, milk production, ovarian activity, irregular estrous cycles, increased occurrence of cystic ovaries, delayed sexual maturity and low conception rates (Cromwell, 1997). Low P in blood has been a contributing factor for typical periparturient diseases of dairy animals such as the downer cow syndrome and post parturient hemoglobinuria (Kacchwaha and Tanwar, 2010). A low dietary phosphorus during dry period into early lactation impairs health and productivity of cows, restricting dietary P supply during the dry period may be effectively used mitigates hypocalcemia during the first wk of lactation (Ringseis *et al.,* 2024). Increasing phosphorus supplementation from 0.4 to 0.6% of the ration had no effect on days to first estrus or services per conception. NRC (2001) has revised the recommendation for dairy cattle from 0.3 to 0.4%. Increasing the dietary concentration of phosphorus above requirement does not improve reproductive performance. Thus, increasing the concentration of dietary phosphorus above requirement (more than 0.38-0.40%) does not improve reproductive performance. A relevant study reported that lowering dietary P from 0.57 to 0.37% did not negatively affect milk production, but did significantly reduce P excretion into environment (Wang *et al*., 2014).

3. Selenium (Se):

Selenium is regarded as important trace element and its deficiency is associated with poor growth, fertility and health in dairy animals. It is involved in normal spermatogenesis and is an essential component of a range of selenoproteins, including enzymes like glutathione peroxidase, thioredoxin reductase and iodothyronine deiodinase. It also plays a vital role in protecting both the intra- and extra-cellular lipid membranes against oxidative damage and protects milk lipids from oxidation (Bhattacharya *et al*., 1988). Both deficiency and excess Se have been demonstrated to be detrimental to normal spermatogenesis. A low level of Se in diet leads to effect on antioxidant system with subsequent detrimental consequences in terms of animal health (Spears, 2000). A marginal Se deficiency in pregnant animals will lead to abortion, or calves will be weak and unable to stand or suckle. Se supplementation reduces the incidence of retained placentas, cystic ovaries, mastitis and metritis. Low Se has also been associated with poor uterine involution, and weak or silent heats. In males, Se supplementation has been shown to increase semen quality (Puls, 1994). Symptoms of chronic Se toxicity include lameness, sore feet, deformed claws and loss of hairs from tail. In pregnant animals, selenium toxicity will produce abortions, stillbirth, weak and lethargic calves as selenium accumulate in the fetus at the expense of the cow (Patterson *et al*., 2003). The dietary requirement of Se for most of the species is about 0.1 ppm. Revised requirement of selenium for better immune response in dairy animals is 0.3 ppm (Weiss, 2002). There are two major sources of Se for animals: Se naturally originating from plants, in the form of seleno-amino acids, including selenomethionine and selenocysteine and inorganic Se in the form of selenate or selenite. Selenized yeast has been reported as more bioavailable source of Se as compared to Se selenite (Juniper *et al.,* 2006). Supplementation of nano selenium improved milk yield, feed efficiency, and milk selenium content of dairy cows (Xiao *et al*., 2024)

4. Zinc (Zn):

Zn is an essential component of over 200 enzyme systems involved in metabolism of carbohydrate and protein, protein synthesis, nucleic acid metabolism, epithelial tissue integrity, cell repair and division, vitamin A and E transport and their utilization. In addition, Zn plays a major role in the immune system and certain reproductive hormones. Zinc has a critical role in the repair and maintenance of the uterine lining following parturition, speeding return to normal reproductive function and estrus. In bulls, a Zn deficiency results in poor semen quality and reduced testicular size and libido (Daniel, 1983). Zn has also been shown to increase plasma β-carotene level which is correlated to improvement in conception rates and embryonic development (Short and Adams, 1988). A good Zn status also improves fertility by reducing lameness, cows more willing to show sign of heat and improved mobility and performance of bulls. A severe Zn deficiency in cattle results in slow growth reduced feed intake, loss of hair, skin lesions (Spears, 1994). A deficiency of Zn in males reduces testicular development and sperm production (Martin *et al.,* 1994). Zn deficiency has been observed in ruminants fed on deficient feedstuffs (Sharma and Joshi, 2005). The recommended dietary content of Zn for dairy cattle is typically between 18 and 73 ppm depending upon the stage of lifecycle and dry matter intake. Cu, Cd, Ca and Fe reduce Zn absorption and interfere with its metabolism (Patterson *et al*., 2003). Requirement of Zn in diet of dairy cows is 40 ppm (NRC, 2001). A Zn supplementation as ZnSO4 and Zn propionate in the diet of crossbred cattle bulls reported improved semen quality in terms of quantitative and qualitative characteristics of semen and organic form of Zn (Zn propionate) showed a better response in improving sperm per ejaculate, mass motility and semen fertility test like bovine cervical mucus penetration (Kumar *et al*., 2006) and better growth and nutrient digestibility in calves supplemented with organic zinc (Rajaei-Sharifabadi *et al*., 2024).

5. Copper (Cu):

Copper serves as a cofactor in metabolic processes and facilitating enzyme formation. High copper levels can enhance animal production. However, excessive Cu intake may lead to its accumulation, causing metabolic disturbances. Copper supplementation can effectively reduce lipid synthesis, especially cholesterol and triglycerides, while enhancing fat oxidation and breakdown by regulating the activity of ATPase copper transporting beta (ATP7B), cyclic adenosine monophosphate (cAMP) levels and endoplasmic reticulum stress, thereby decreasing lipid accumulation (Fu *et a*l., 2024). Cu is a necessary component of number of enzymes including superoxide dismutase, lysyl oxidase and thiol oxidase. Action of these enzymes is to scavenge free radicals and thus prevent tissue susceptibility to infections, increase structural strength of connective tissues and blood vessels, and increase strength of horn and hooves. Cu also plays an important role in the immune system. Cu and Zn have a significant correlation with reproductive hormones (progesterone and estradiol) (Prasad *et al*., 1989). A Cu deficiency in cattle is generally due to the presence of dietary antagonists, such as S, Mo and Fe that reduce Cu bioavailability. Deficiencies of Cu have also been associated with retained placenta, embryonic death and decreased conception rates and anestrus (Mudgal *et al*., 2014). Feeding a total of 10 to 15 ppm copper in the ration dry matter or supplementing with 10 ppm copper should meet dairy cattle needs. If rations contain antagonists such as elevated Fe, S, or Mo, replacing 35 percent of supplemental copper with organic copper sources improved Cu availability. The following mineral ratios may be helpful in maintaining Cu levels in blood: Zn: Cu 4:1, Cu: Mo 6:1 and Fe: Cu 40:1 (Hutjens, 2000). Amino acid chelates of Cu, Mn and Zn have been reported to reduce services per conception significantly in dairy cows (Bosseboeuf *et al.*, 2006).

6. Manganese (Mn):

Mn is an essential nutrient for dairy animals like other minerals. There is large variation in Mn levels in feedstuffs. Fodders were generally adequate in Mn but concentrate ingredients may be deficient (Bhanderi *et al.,* 2014). Generally, legume and grass hays have more Mn than corn or corn silage and Mn is reported to be more available in hay than silage (Puls, 1994). Mn is an activator of enzyme systems in the metabolism of carbohydrate, fats, protein and nucleic acids. Mn appears to have a vital role in reproduction. It is necessary for cholesterol synthesis (Kappel and Zidenberg, 1999), which in turn is required for synthesis of the steroids, estrogen, progesterone and testosterone. Insufficient steroid production results in decreased circulating concentrations of these reproductive hormones resulting in abnormal sperm in males and irregular estrus cycles in females. The corpus luteum has high Mn content and thus may be influenced by Mn deficient diet. Concentration of Mn in vagina is higher in cycling than in anestrous animals. A deficiency of Mn may be associated with suppression of estrus, cyclic ovaries and reduced conception rate (Patterson *et al.,* 2003). The maintenance requirement for absorbed Mn was set at 0.002 mg/kg of body weight (1.2 mg/day for an average Holstein cow), the growth requirement was set at 0.7 mg/kg of growth, pregnancy requirement was set at 0.3 mg/d, and the lactation requirement was set at 0.03 mg/kg of milk (NRC, 2001). Gestating cattle may need up to 50 mg of Mn/Kg of DM because it helps in skeletal cartilage and bone formation of fetus (Schefers, 2011) and this value is higher than 40 mg of Mn/Kg of DM recommended by NRC (1989).

7. Iodine (I):

Iodine is an essential trace element for dairy animals. Iodine is incorporated into the thyroid hormones, which have multiple functions as cell activity regulators. I deficiency affects reproductive capacity, brain development and progeny as well as growth. I requirement is important in the development of fetus and maintenance of general basal metabolic rate by synthesis of thyroid hormone. I deficiency leads to delay in puberty, suppressed or irregular estrus (Puls, 1994), failure of fertilization, early embryonic death, still birth with weak calves, abortion, increased frequency of retained placenta in females and decrease in libido and deterioration of semen quality in males. Findings of Pattanaik *et al.* (2011) reported that 0.1 mg/d extra supplementation of I as effective strategy to counteract functional disorders of the thyroid and associated adverse effects induced in goats by feeding of leucaena leaf meal. Inadequate thyroid function reduces conception rate and ovarian activity. Thus, I deficiency impairs reproduction and iodine supplementation has been recommended when necessary to ensure that cows consume 15-20 mg of iodine each day. Recently, Excessive I intakes have been associated with various health problems including abortion and decreased resistance to infection and disease. Signs of subclinical iodine deficiency in breeding females include suppressed estrus, abortions, still births, increased frequency of retained placentas and extended gestation periods (Hess et al., 2008). A number of studies have reported beneficial effect of lugol's iodine in treatment of silent estrus, repeat breeding and conception rate (Ahmad and Elsheikh, 2014).

8. Cobalt (Co):

Ruminants need cobalt to meet the vitamin B_{12} requirements of both the ruminal bacteria and the host animal. Vitamin B_{12} is a water-soluble vitamin produced by rumen microbes. A depletion of cobalt and vitamin B_{12} at parturition through colostrums causes depressed milk production and colostrums yield and quality (Patterson *et al.,* 2003). Early lactation cows have reduced vitamin B_{12} status due to increased demands of lactation (Girard and Matte, 1999). Co deficiency is associated with an increased incidence of silent heats, a delayed onset of puberty, nonfunctional ovaries, and abortion. Inadequate cobalt levels in the diet have been correlated with increased early calf mortality. Mn, Zn, I and monensin may reduce cobalt deficiency. The recommendation for cobalt requirement in dairy cows varies between 0.10 mg/kg DM (NRC 2001) and 0.20 mg/kg DM (GfE, 2001). Cobalt supplementation of up to 50 mg daily in Holstein cow have been reported to improve feed digestion in heat stress depression in feed digestibility, fat yield and milk yield (Karkoodi, 2010). Recent studies reported that oral Co acetate administration to lactating cows and ewes decreased milk concentrations of fatty acids containing a cis-9 double bond, and inhibition of stearoyl-coenzyme A desaturase activity (Frutos *et al.,* 2014), thus play a role in mammary lipogenesis in ruminants and responsible for the majority of cis-9,trans-11 conjugated linoleic acid and a significant amount of cis-9 18:1 secreted in bovine (Mosley *et al*., 2006).

9. Potassium (K):

K is the third most abundant mineral element in the animal body after Ca and P. K concentrations in cells exceed the concentration of Na by 20 to 30 times. Outside the cell the reverse is true. K is about 5% of the total mineral content of the body. The dairy cow's minimum requirement for K is 0.90% to 1.0% of the ration on DM basis (NRC 2001). The maximum tolerable level is about 3.0%. Feeding high levels of K may delay the onset of puberty, delay ovulation, effect corpus luteum development and increase the incidence of anestrous in heifers. In dry period during the last 2 to 3 weeks prepartum can predispose the fresh cow to milk fever, displaced abomasum, uterine problems, and other metabolic disorders (DeGaris and Lean, 2008). The K requirement for gestating and lactating sows is 0.20 percent. K requirement increases in diets with higher Na and Cl levels. Ruminants have a higher K requirement than nonruminants. K is essential for rumen microorganisms. The suboptimal level of K in the ration decreases feed intake in ruminants. The K requirement in tropical summer is increased as high as 1.9% for high producing cows.

10. Chromium (Cr):

Cr improves sensitivity of insulin, resulting in increased uptake of glucose and amino acids by cells in the body (Short and Adams, 1988). Dietary energy intake in early lactation does not meet energy demands for maintaining body reserves and milk yield. A low serum insulin, high glucagon and growth hormone (Herbein et al., 1985), and high plasma NEFA concentrations (Grummer, 1993) in early lactation dairy cows indicates high catabolic activities and negative energy balance. This leads to increased gluconeogenesis and glycogenolysis in the liver and increased mobilization of protein reserves from muscle tissue (Collier et al., 1984). Several studies reported insulin resistance begins before parturition and continues during early lactation. Thus, during the periparturient period, insulin resistance may be an important factor in the initiation of catabolic activities. At this stage, Cr supplementation (0.5 ppm) may enhance the action of insulin sensitivity and, consequently decrease NEFA and liver triglyceride concentrations in blood and improve glucose tolerance, which may result in improvement of performance and production during the periparturient period (Kumar et al., 2023).

11. Salt (NaCl):

Salt contains sodium (Na) and chloride (Cl) and is often supplemented in concentrate or as free lick. Na is an essential element for animals but is not required by plants. Na functions in maintaining osmotic balance, in cellular uptake of glucose and in amino acid transport (NRC, 1989). Lactating dairy animals in the tropics may require more Na due to the hot and humid climatic conditions. The daily salt requirements for dairy cattle are met easily by adding 1 percent salt to concentrate mixture and offering additional salt lick. Lactating cows need 2 g salt/kg milk production. Dry cows need 40 g salt daily or 0.3% Na per kg DM. Salt deficiencies can affect the efficiency of digestion and indirectly the reproduction performance of cows. Na and Cl content of feedstuffs often not enough to meet animal requirements and should be provided free choice at all times. Thiangtum *et al.* (2011) recommended 1.2 g of Na/kg of DM for dairy cows under tropical conditions.

Conclusion:

Minerals play essential roles in bone and tooth formation, muscle and nerve function, and maintaining overall health and reproduction. They are vital components of various enzymes, vitamins, hormones, and respiratory pigments, acting as cofactors in metabolism and enzyme activation. Mineral requirements of animal depend upon age, species, breed, physiological conditions of animals. However, mineral interactions, toxicities and bioavailability from different sources must be taken into account in dairy animal nutrition. The organic and nano sources of minerals to minimize environmental pollution with concurrent demand for higher bioavailability for immunity and better reproduction need to be explored.

Table 1. Mineral Requirement (DM Basis) of Indigenous Cows:

Mineral	Dietary Requirement	Mineral	Dietary Requirement
Calcium	0.65-0.80%	Iron	50 mg/kg
Phosphorus	0.35-0.45%	Copper	12-16 mg/kg
Magnesium	0.25-0.35%	Cobalt	0.11 mg/kg
Sodium	0.28-0.45%	Manganese	45-55 mg/kg
Chlorine	0.28-0.35%	Zinc	45-55 mg/kg
Sulphur	0.20-0.22%	Selenium	0.3-0.5 mg/kg
Potassium	1.0-1.5%	Chromium	0.3-.05 mg/kg
Iodine	0.45-0.60 mg/kg	Nickel	3 mg/kg*

(Adopted from Bhanderi *et al.,* 2014, Kumar, 2015, Kumar *et al.*, 2023)

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Chapter-8

Precision Feeding for Economic and Eco-friendly Livestock Production

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Introduction:

Traditional livestock feeding programs are least-cost formulated to meet the nutritional requirements of either the average or best performing animals in a population, resulting in over and under feeding animal within the same group. Maximum growth is relatively easy to achieve through overfeeding of nutrients. However, it is not, a cost effective strategy. Precision feeding is a concept that allows the right amount of feed with the right composition to be provided at the right time to each animal of the herd for high-quality and efficient production, while ensuring the lowest possible load on the environment (Niemi *et al.*, 2010). Precision nutrition consists of meeting the nutrient requirements of animals as accurately as possible in the interest of a safe, high-quality and efficient production, besides ensuring the lowest possible load on the environment (Naas, 2001). This is an innovative area of animal nutrition, is a unique combination of traditional animal nutrition science, new animal nutrition knowledge incorporating natural science areas and informatics. Precision nutrition is also called “information intensive nutrition”, because, it uses the latest scientific findings in feed formulation in order to meet with the maximum accuracy the unique nutrient requirements of a given herd kept under given conditions (Sifri, 1997).

Precision Feeding Technologies:

Precision feeding requires accurate knowledge of the nutritional value of feedstuffs and animal nutrient requirements, the formulation of diets in accordance with environmental constraints, and the gradual adjustment of the dietary nutrient supply to match the requirements of the animals. The essential elements for precision feeding in livestock production systems include:

- Precise evaluation of the nutritional potential of feed ingredients,
- Precise determination of nutrient requirements,
- Formulation of balanced diets that limit the amount of excess nutrients,
- Concomitant adjustment of the dietary supply and concentration of nutrients to match the evaluated requirements of each animal in the herd.

1.1 Precise Evaluation of the Nutritional Potential of Feed Ingredients:

Determination of the nutritive value of dietary ingredients for livestock is a difficult and tedious task. Previously total chemical nutrient content was used to characterize the nutritional potential of dietary ingredients in livestock feeds. The progression of the characterization of the nutritional potential of feed ingredients and animal requirements from a total to a digestible basis, and then to an available or net basis, allows for the formulation of diets with nutrient levels that are closer to the animals' requirements without the use of excessive safety margins. The careful assessment of the bioavailability of each dietary nutrient is critical for evaluating the nutritional value of feed ingredients for estimating the animals' requirements (Stein *et al.,* 2007). Additionally, feed processing technologies like grinding, heat treatment and the addition of enzymes are also important factors that should be taken into account when assessing the potential of nutritious foods. The precise evaluation of the nutritional potential of feed ingredients is required for livestock precision feeding.

1.2 Precise Estimation of Nutrient Requirements:

Nutrient requirements are defined as the amounts of nutrients needed for specified production purposes, which in farm animals are production outputs such as growth rate, protein deposition, milk yield, etc. The least-cost feed formulation methods generally used by the industry try to minimize the cost of the feed mix, without taking into account the environmental consequences of excess nutrients (Patience *et al.*, 1995) and animal responses (Sauvant, 1994). Thus, a feed formula may be nutritionally adequate and economically optimal but may still provide significant amounts of excess and unavailable nutrients. Linear programme of feed formulations works on assumptions of additivity (the nutritional contribution of a blend of ingredients is the sum of the nutrient contribution of each ingredient), proportionality (the change in the contribution of an ingredient in a blend changes the nutritional value and cost of the blend in proportion to the change) and divisibility (the incorporation of an ingredient in a mixture is divisible indefinitely).

1.3 Adjustment of the Nutrient Supply to Match the Requirements of a Group of Animals:

Usually growing animals are allowed to consume feed *ad libitum* from weaning until they reach market weight. It is generally accepted that pigs consume feed to meet their energy requirements for maintenance and growth (Black *et al.*, 1986). In all cases, however, energy requirements increase faster than the requirements for most other nutrients, with the result that the optimal concentration of nutrients in diets for growing animals progressively decreases over the growing period. After the proper characterization of the nutritional potential of feed ingredients, the proper estimation of population nutrient requirements and the formulation of balanced diets, the accurate adjustment of the nutritional content of the feed to match these requirements is required and phase feeding is the most common technique.

(a) Phase Feeding:

To optimize the production and to minimize nutrient waste, the animal's diet should be changed continuously to match its requirements. Phase feeding involves feeding a number of successive diets, each differing in its protein, energy or amino acid balance in order to match the evolving nutritional requirements of the animals. Phase feeding programs match the animal's nutrient requirements as they change with age or size and reduce the time animalsare fed a deficient or excessive amount of nutrients. In order for this strategy to be successful, accurate knowledge of the requirements of the animals is required and more intensive management may have to be applied in order to match supply to requirement. However, increasing the number of feeding phases increases the costs of feed storage and management.

(b) Split-Sex Feeding:

Feeding the two sexes separately during the growing and finishing period is known as split-sex feeding. Separating the sexes has several benefits. Livestock grow at different rates and utilize feed differently. e.g. gilts are leaner than barrows when they reach market weight. Because of their leaner carcasses, gilts respond to higher dietary levels of protein than do barrows. Thus, the major advantage of penning the sexes separately is that gilts can be fed higher levels of protein than barrows during the finishing period. There are claims that separately penned barrows and gilts show less aggressive behavior, experience less fighting, exhibit less competition for feed, and have more uniform gains. Also, the marketing of more uniform pigs results in higher market prices (Cline *et al*., 2011).

1.4 Individual Feeding Strategies for Precision Feeding:

One of the limitations of group feeding is that all animals are fed a unique feed during relatively long periods. Determining the optimal composition of this complete feed is complex, and when population responses are optimized, most of the animals in the populationwill receive more nutrients than they need, and a small portion of the population will be fed above requirements. Nutrient requirements within an animal population vary greatly, and this variation is affected by many factors such as genetic variation, management and health. Feeds formulated with large safety margins and large amounts of excess nutrients for optimal response in heterogeneous populations (e.g. genetic potential, sex and weight) promote the excretion of nutrients. In these situations, feeding animals individually with daily tailored diets reduces feeding costs and improve dietary nutrient efficiency. Feeding animals individually according to genetics, gender and actual feed intake and growth patterns can help simplify the estimation of nutrient requirements and reduce excess nutrients (Pomar *et al.*, 2009).

2. Precision Feeder:

Accurately and automatically measuring the amount of feed used per day per animal or distinct group of animals is extremely important, as the feed conversion efficiency is the main driver of profitability of all meat producing livestock enterprises. In Australia, an innovative feed sensor was developed recently that can quite precisely measure and control the amount of feed delivered to individual feeders. This feeder automatically provides daily tailored feeds to each pig in the population, estimating its nutrient requirements each day based on individual feed intake and body weight measurements. The new fully automated and intelligent feeder will integrate state-of-the-art scientific knowledge in feed formulation, pig growth modelling, the prediction of the environmental load of the produced slurry, and so on. However, this automatic feeder needs to precisely determine the nutrient amounts that each pig requires every day to satisfy its requirements and optimize growth.

3. Precise Feeding to Reduce Environmental Pollutants:

The goal of efficient and productive feeding of animals, within economic and environmental constraints, is to provide essential available nutrients for maintenance and production while minimizing excess amounts. Often rations are formulated with a "safety margin" by increasing the concentrations of nutrients beyond that needed to meet requirements, possibly by as much as 30 to 50%. This results in excretion of the excess nitrogen (N) and phosphorus (P). The best ways to reduce the amount of nutrients excreted by animals include matching the amount consumed to that needed to meet the animals' requirements (precision feeding) and increasing the efficiency of utilization of the nutrients consumed. One method of reducing the manure produced is to improve the digestibility of feeds through technological treatments of the feeds like particle size reduction or through the addition of enzymes (Singh, 2008) to the feed.

Benefits of Precision Feeding:

The long-term benefits of precision feeding offer following advantages:

- Reduce feed costs by improving nutrients utilization
- Reduce environmental pollution by reducing excretion of nutrients (nitrogen and phosphorus) in excreta
- Enhance food safety.

- The opportunity to reduce labor requirements through automatic monitoring

Challenges of Precision Feeding:

Precision feeding including new management systems should be developed in order to fulfil the need of individual animals, taking into account their physiological, health and welfare status, and their genetic make-up. There is a great potential for the use of precision feeding systems within the pork industry. However, implementation of precision feeding systems presents, significant challenges which are related to their complexity (e.g., individual estimation of nutrient requirements), reliability (e.g., using electronic devices in farms) and cost effectiveness. The potential downside is that we may have slight reductions in growthrate as we feed closer to the true requirements. These challenges will need to be addressed in the future making it a practical and viable option for producers throughout the world.

Conclusion:

Precision feeding involves the use of feeding techniques that allow the provision of the right amount of feed with the right composition at the right time to each animal in the herd. Precision nutrition (also called "information intensive nutrition") is the practice of meeting the nutrient requirements of animals as accurately as possible in the interest of a safe, high-quality and efficient production, while ensuring the lowest possible load on the environment. Thus, precision feeding is an essential approach to improve nutrient utilization and thus reduce feeding cost and nutrient excretion for sustainable and eco-friendly livestock production.

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Chapter-9

Technologies Adopted for Feeding of High Yielding Dairy Animals

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Introduction:

High-yielding dairy animals play a crucial role in the dairy industry, as they contribute to higher milk yields, making milk and dairy products more readily available for consumers. The milk production capacity of cows can vary based on factors such as breed, genetics, nutrition, health, and management practices. Feeding high-yielding dairy animals is a critical aspect of modern dairy farming. They require careful attention to their nutritional needs. These animals have a high demand for energy, protein, vitamins, and minerals to support their milk production, body maintenance and reproduction. To ensure optimal nutrition and productivity, and to maximize the supply of nutrients for dairy animals, with respect to requirement for their growth, production and reproduction, continuous efforts are required to increase the efficiency of existing feed resources through active and passive manipulations in rumen and feed modifications. There are various technologies and management practices which can be adopted for feeding high yielding animals to get more production.

1. Total Mixed Ration (TMR):

TMR is a feeding strategy that involves combining all necessary ingredients in a balanced ratio to create a complete feed for dairy animals. In this system, all the feed ingredients, including forages, concentrates, minerals, and vitamins are thoroughly mixed together in predetermined proportions to form a complete and homogeneous ration. The TMR is then fed to the animals, ensuring that each mouthful contains the right balance of nutrients required for their specific production stage and performance goals. Key features and benefits of the Total Mixed Ration (TMR) system include:

i. **Nutritional Balance:** TMR allows for precise control over the feed composition, ensuring that animals receive the right combination of energy, protein, fiber, minerals, and vitamins, tailored to their specific needs.

ii. **Reduced Sorting:** Since all the ingredients are mixed together, animals cannot easily pick and choose their preferred feed components, reducing feed wastage and promoting more uniform nutrient intake.

iii. **Improved Feed Efficiency:** The balanced diet provided by TMR can lead to improved feed efficiency, as animals efficiently utilize the nutrients they receive, resulting in better growth, milk production and reproductive performance.

iv. **Consistency:** With TMR, the feed composition remains consistent, eliminating variations that might occur when feeding different ingredients separately.

v. **Time and Labor Efficiency:** Mixing the ration in advance saves time and labor compared to individually feeding different components.

vi. **Reduced Metabolic Disorders:** TMR can help prevent certain metabolic disorders, such as ruminal acidosis, which can result from sudden changes in the diet.

vii. **Enhanced Milk Production:** High-yielding dairy cows, in particular, benefit from TMR as it provides the necessary nutrients to support their demanding milk production levels.

2. Bypass Nutrient Technology:

This involves feed management through passive rumen manipulation, by which reducing ruminal degradation of nutrients and bypassing the nutrients from rumen, get digested enzymatically and absorbed from the lower gastrointestinal tract.

i. **Bypass Protein**: Also known as undegradable or rumen-protected protein, refers to a specific type of protein that resists degradation in the rumen of ruminant animals (such as cows, sheep, and goats). Bypass protein is designed to pass through the rumen unaffected, reaching the animal's lower digestive tract, particularly the small intestine. Through this approach, there is a significant reduction in the wasteful ammonia production in the rumen from dietary proteins and a proportionate increase in the supply of amino acids to the host ruminant for productive/reproductive purposes *viz.* growth, reproduction and milk production, with an overall increase in the efficiency of protein and energy utilization. Bypass protein sources are often protected or treated by various methods to makes them resistant to microbial degradation in the rumen, allowing them to pass through to the small intestine. There are several methods to protect protein from rumen degradation and create bypass protein:

a. **Heat Treatment:** Treating protein sources with heat can denature or alter the protein structure, making them less susceptible to microbial degradation in the rumen.

b. **Chemical Treatment:** Certain chemicals can be used to protect protein from rumen degradation. These chemicals form bonds with the protein, preventing microbial enzymes from breaking it down in the rumen.

c. **Encapsulation:** Protein sources can be encapsulated in a protective coating, often using fats or other substances, which keeps the protein safe from rumen microbes until it reaches the small intestine.

By providing bypass protein in the diet, dairy farmers and livestock producers can enhance the efficiency of protein utilization in ruminant animals. This can lead to improved milk production, growth, and overall performance, while also reducing nitrogen waste in the environment, as the excess protein excreted in the manure is reduced.

ii. **Bypass Fat:** Also known as rumen-protected fat or inert fat, is a type of fat that resists degradation in the rumen of ruminant animals. In the rumen, microbes break down dietary fats along with other nutrients through a process called ruminal biohydrogenation. However, certain fats, particularly saturated or hydrogenated fats, can be protected or treated to bypass microbial degradation in the rumen. This bypass fat then passes through to the lower digestive tract, where it can be absorbed and utilized in the small intestine. The primary purpose of including bypass fat in ruminant diets is to provide a concentrated source of energy. Bypass fat can be particularly beneficial for high-producing dairy cows and other ruminants with high energy demands, such as those in late gestation or early lactation. There are various forms of bypass fat available, including calcium salts of fatty acids, hydrogenated fats, and encapsulated fats. These forms are designed to be stable in the rumen and only break down and release energy in the small intestine.

3. Area Specific Mineral Mixtures (ASSM):

The under supply of minerals in livestock ration is the most common feature. The deficiencies of certain minerals may not only affect crop yields but also their availability from such forages/ feed may be inadequate for requirement of livestock. Animal Nutrition Surveys were conducted in different parts of india by various agencies in order to find out specific mineral deficiency for particular area. Area Specific Mineral Mixtures (ASSM) could imply customized or region-specific mineral mixtures formulated to meet the specific mineral deficiencies or imbalances prevalent in a particular geographical area. The mineral requirements of animals, including cattle, sheep, goats, and other livestock, can vary depending on factors such as soil composition, forage quality, water quality, and other environmental conditions in a specific area. Customizing mineral mixtures to address the unique needs of animals in a particular region can help ensure optimal health, growth, and productivity. The precise formulation and levels of the minerals in an area-specific mixture would depend on local soil and forage analyses, along with the specific needs of the target animal species and production goals.

4. Precision Feeding:

Precision feeding is an advanced approach to animal nutrition and management that uses modern technology and data-driven methods to optimize feeding practices and improve the overall efficiency, health, and productivity of livestock. It refers to the practice of tailoring individualized diets based on the specific nutritional requirements of each animal. This approach utilizes advanced technologies to determine the nutrient needs of individual cows and provide precise feed formulations accordingly. In precision feeding, various technologies, sensors, and data analytics are employed to monitor individual animals or groups of animals, collect real-time data, and make informed decisions about their nutritional needs. This approach considers the unique requirements of each animal, taking into account factors such as age, weight, production stage, health status, and environmental conditions. Key components of precision feeding include:

i. **Data Collection:** Collection of data from various sources, including wearable sensors, RFID tags, automated feeding systems, environmental sensors, and other monitoring devices. These technologies track feed intake, body weight, milk production, activity levels, and other relevant parameters.
ii. **Data Analysis and Decision Support:** Advanced analytics and artificial intelligence are used to process the collected data and generate actionable insights. Algorithms can identify patterns, predict animal behavior, and assess nutritional needs, helping farmers make informed decisions about feed formulations and management practices.
iii. **Customized Ration Formulation:** Based on individual animal data and nutritional requirements, precision feeding allows for the formulation of customized diets tailored to each animal's specific needs. This optimization helps improve feed efficiency, reduce wastage, and enhance animal health and performance.
iv. **Automated Feeding Systems:** Precision feeding often involves automated feeding systems that can deliver the precise amount and type of feed to each animal based on their nutritional requirements. These systems ensure that animals receive the right nutrients at the right time, promoting better growth, reproduction, and milk production.
v. **Real-Time Monitoring and Alerts:** Continuous monitoring and alerts enable early detection of health issues or deviations from the desired production targets, allowing prompt intervention and timely adjustments in feed management.

Benefits of Precision Feeding:

- **Improved Feed Efficiency:** Animals receive the optimal amount and quality of feed, minimizing wastage and maximizing nutrient utilization.
- **Enhanced Animal Health:** Early detection of health issues and precise nutritional management can lead to better overall health and welfare of the livestock.
- **Increased Productivity:** Precision feeding can result in higher growth rates, improved milk production, and better reproductive performance.

- **Environmental Sustainability:** Reducing feed wastage and optimizing nutrient utilization contribute to a more sustainable and environmentally friendly livestock production system.

5. **Feed Additives:**

Feed additives are substances added to animal feeds to enhance the nutritional value of the feed, improve animal health and performance, and/or prevent or mitigate specific health issues. These additives can be natural or synthetic compounds, and they serve various purposes based on the needs of the animals and the goals of livestock producers. There are several categories of feed additives, each designed to address different aspects of animal nutrition and health:

i. **Nutritional Additives:** These additives provide essential vitamins, minerals, amino acids, and other nutrients that may be deficient or insufficient in the animal's diet. Common examples include vitamins A, D, E, and B-complex, minerals like calcium, phosphorus, zinc, and amino acids such as lysine and methionine.

ii. **Growth Promoters:** Growth-promoting additives aim to enhance animal growth and development, resulting in improved weight gain and feed efficiency. Some growth promoters function as natural hormones, while others are synthetic compounds. However, the use of certain growth-promoting additives may be regulated or prohibited in some regions.

iii. **Feed Enzymes:** Enzymes are included in the feed to enhance nutrient digestion and absorption. They can break down complex molecules like non-starch polysaccharides (NSPs) in grains and improve nutrient utilization, especially in monogastric animals like pigs and poultry.

iv. **Probiotics and Prebiotics:** Probiotics are beneficial live microorganisms (e.g., beneficial bacteria) that improve the gut microbial balance, promote digestion, and support immune function. Prebiotics, on the other hand, are non-digestible components that selectively stimulate the growth and activity of beneficial gut bacteria.

v. **Antioxidants:** Antioxidant additives help protect animal cells from oxidative stress caused by free radicals. Common antioxidants include vitamin E, vitamin C, and selenium.

vi. **Acidifiers:** Acidifiers are additives that reduce the pH of the animal's gastrointestinal tract, promoting a healthier gut environment and inhibiting the growth of harmful bacteria.

vii. **Mycotoxin Binders:** Mycotoxin binders adsorb mycotoxins (toxic compounds produced by fungi) in the feed, preventing them from being absorbed by the animal and reducing the negative effects of mycotoxin contamination.

viii. **Coccidiostats and Antibiotics:** These additives help control or prevent infections caused by specific parasites (coccidiostats) or bacteria (antibiotics). The use of antibiotics as feed additives is often regulated to prevent antibiotic resistance.

ix. **Rumen Modifiers:** These additives are used in ruminant diets to modify rumen fermentation and improve nutrient utilization, particularly in high-yielding dairy cows.

6. Ration Balancing:

Ration balancing is the process of formulating a complete and balanced diet for animals, ensuring that their nutritional requirements are met based on factors such as age, weight, production stage, breed, and environmental conditions. The goal of ration balancing is to provide animals with the optimal amount and proportion of nutrients to support their growth, maintenance, reproduction, and overall health. The steps involved in ration balancing include:

i. Determine Nutritional Requirements: The first step is to understand the specific nutritional requirements of the animals. These requirements vary depending on the species, production goals (e.g., milk production, meat production), growth stage (e.g., young, adult, pregnant, lactating), and activity level.

ii. Assess Feed Ingredients: The next step is to evaluate the available feed ingredients, including forages, grains, protein sources, and mineral supplements. Each ingredient has its own nutritional composition, and its inclusion in the diet must be based on its nutrient content and cost-effectiveness.

iii. Formulate the Ration: Using the information on nutritional requirements and feed ingredient composition, a ration is formulated to meet the specific needs of the animals. The goal is to balance the amounts of energy, protein, fiber, minerals, and vitamins in the diet.

iv. Consider Feed Intake and Palatability: The formulation should also take into account the expected feed intake of the animals. Some ingredients may limit the consumption of the diet if they are unpalatable or poorly digestible.

v. Consider Animal Health and Production Goals: Ration balancing should also address any health considerations or specific production goals, such as supporting immune function, optimizing milk production, or promoting weight gain.

vi. Cost Optimization: Balancing a ration also involves optimizing the cost of the diet while meeting the nutritional requirements. This may involve finding cost-effective sources of nutrients and avoiding unnecessary over-supplementation.

vii. Regular Monitoring and Adjustment: Ration balancing is not a one-time process. It requires periodic evaluation and adjustment based on factors such as changes in animal weight, production level, environmental conditions, and availability of feed ingredients. Ration balancing is particularly crucial in intensive animal production systems, such as dairy farms and feedlots, where the efficient use of feed directly impacts animal performance and profitability. Properly balanced rations contribute to improved growth rates, higher milk production, enhanced reproductive performance, and overall animal health and welfare.

7. Forages:

Forages play a vital role in the diets of high-yielding dairy animals, providing essential nutrients and fiber. To maximize the quality and availability of forages, dairy farmers employ various technologies:

a. **Precision Seeding:** Precision seeding involves using advanced seeding equipment to achieve precise seeding rates and distribution of forage crops. This ensures optimal plant density and uniformity, leading to improved forage quality and yield. Precision seeders often utilize GPS technology and variable rate seeding to precisely place seeds in the field.

b. **Irrigation Systems:** Efficient irrigation systems, such as drip irrigation and precision sprinklers, help maintain optimal moisture levels in the forage fields. These systems use soil moisture sensors and weather data to deliver the right amount of water to the crops, reducing water waste and improving forage growth.

c. **Harvesting Equipment:** Modern harvesting equipment, including forage harvesters and balers, are designed to maximize efficiency and forage quality. These machines incorporate advanced technologies like moisture sensors, yield monitors, and automated controls to optimize the harvesting process. Prompt and precise harvesting reduces nutrient losses and preserves forage quality, enhancing its nutritive value for high-yielding dairy animals.

8. Ensiling:

Silage is a popular method of preserving forages for feeding dairy animals. Technologies associated with ensiling help maintain the quality and nutrient content of silage:

- **Silage Inoculants:** These are microbial additives containing lactic acid bacteria and enzymes that promote a rapid and efficient fermentation process, reducing nutrient losses and improving the preservation of silage.
- **Proper Packing:** Advanced packing techniques, such as the use of heavy tractors, packer plates, and tire pressure sensors, ensure proper compaction of silage. Well-compacted silage reduces oxygen presence, promoting anaerobic fermentation and inhibiting spoilage organisms.

- **Silage Covers:** Impermeable and oxygen barrier covers are used to protect silage from air and moisture ingress, reducing spoilage and maintaining its nutritional value during storage.

9. Nutritional Modelling:

Nutritional modelling refers to the use of mathematical and computational techniques to simulate and predict the nutrient requirements, feed utilization, and overall nutritional status of animals. This approach involves developing mathematical models that represent the complex interactions between animal physiology, feed composition, and nutrient metabolism. By inputting these parameters, farmers can obtain accurate predictions of nutrient requirements and formulate precise diets accordingly. The main objectives of nutritional modeling are:

i. **Optimizing Feed Efficiency:** By simulating nutrient utilization and requirements, nutritional models can help identify the most efficient diets for different animal species and production stages. This optimization aims to maximize animal performance while minimizing feed costs and reducing waste.

ii. **Precise Ration Formulation:** Nutritional models assist in formulating well-balanced rations tailored to the specific needs of individual animals or groups of animals. The models consider factors such as age, weight, growth rate, production goals, and environmental conditions.

iii. **Understanding Nutrient Interactions:** Nutritional models can explore how different nutrients interact with one another and how their levels impact animal health and productivity. For instance, understanding the relationship between calcium and phosphorus can help prevent mineral imbalances in livestock.

iv. **Predicting Growth and Production:** By integrating growth and production data with nutritional inputs, models can predict the growth rates and performance of animals under various feeding scenarios.

v. **Designing Feeding Strategies:** Nutritional modelling enables the evaluation of different feeding strategies and their potential effects on animal health and performance. This includes assessing the impact of changes in diet composition, feed additives, and environmental conditions.

vi. **Investigating Nutritional Challenges:** Models can be used to explore the impact of nutritional challenges or deficiencies on animal health, reproduction, and immunity, helping to identify potential solutions.

The development of nutritional models requires accurate data on animal physiology, feed composition, nutrient digestibility, and metabolism. These models are often constructed using mathematical equations based on established scientific knowledge of animal nutrition and metabolic pathways. Advanced computer software and computational tools are employed to simulate and analyze the complex interactions within the model. Researchers and nutritionists use these models to test hypotheses, generate predictions, and gain insights into the intricacies of animal nutrition and metabolism.

In conclusion, the feeding of high-yielding dairy animals involves the adoption of numerous technologies and management practices. From precision feeding and total mixed ration to forage management and feed additives, these technologies play a crucial role in optimizing nutrition, improving productivity, and ensuring the overall health and well-being of dairy animals. Advanced tools such as NIRS, computerized systems, precision feeding equipment, and nutritional modeling further enhance the precision and efficiency of feeding high-yielding dairy animals.

Chapter-10

Poultry Nutrition: Basic Concepts and Recent Advances

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Introduction:

The term "poultry" refers to various domesticated bird species, including chickens, turkeys, ducks, geese, game birds like quail, pheasants, and partridges, as well as ratites such as emus and ostriches. Poultry production is globally recognized as an important aspect of animal agriculture. It is the largest animal protein producer industry in world and supply high quality protein (meat and egg) for ever increasing human population. Poultry industry has advanced remarkably over the past five decades. Chicken is widely regarded as a highly accessible and efficient protein source due to its rapid production cycle and space-efficient farming requirements. Broiler chickens exhibit the highest feed conversion efficiency among livestock, contributing to the sector’s prominence. Advances in genetics and nutrition have allowed broilers to reach an average market weight of 2-2.5 kg in 33–35 days, while modern layer hens are capable of producing around 330 eggs over 52 weeks (Havenstein *et al.*, 2003). Advancements in genetic nutritional research are driven by a range of sophisticated techniques developed by scientists in both academic and industrial settings. Nutritional research primarily focuses on deepening our understanding of ingredients that support bird growth and health, identifying the nutritional needs of different bird species and categories, and tailoring these nutritional requirements to suit varying conditions, including environmental factors. This chapter discusses the basic poultry nutrition as well as nutritional research efforts and some notable advance research techniques employed in poultry nutrition.

Basic Poultry Nutrition:

Poultry need certain basic nutrients for proper growth, development and generation of energy. These nutrients are water, carbohydrates, fats, proteins, minerals and vitamins.

Water:

Earlier water was not considered as nutrient but now it has been accepted one of the most important nutrients. It plays an important role in the body of an animal or bird. An animal can live without food longer than it can live without water. A shortage of water for just a few hours can result in reduced egg production in a laying flock, so clean water should be provided to birds all the times. The water requirement is mainly dependent on age, functional status, environmental temperature and other factors (ICAR 2013). Water plays a crucial role in digestion by softening feed and aiding its movement through the digestive tract. It makes up about 90% of blood, which is responsible for transporting nutrients and waste between the digestive system and the body's cells. Since birds lack sweat glands, water also helps regulate body temperature through evaporative cooling, primarily via the air sacs and lungs during rapid breathing. Additionally, a newly hatched chick consists of approximately 80% water. Even though this percentage decreases as a bird gets older, the need for water always remains. There is no precise quantity requirement for water because there are several factors that affect the amount of water a bird needs, viz., age, body condition, diet, temperature, water quality, and humidity. As a general rule of thumb, poultry typically consume about twice as much water as the amount of feed they eat.

Carbohydrates:

Carbohydrates (compounds with carbon, hydrogen, and oxygen) are the main energy source for animals, and they make the largest portion of a poultry diet. Carbohydrates are eaten in the form of starch, sugar, cellulose, and other non-starch compounds. Poultry do not digest cellulose and the non-starch compounds (crude fibre) properly. Important sources of carbohydrates in poultry feed ingredients include energy concentrates such as corn, oats, wheat, barley, sorghum, and milling by-products. The intake of energy by a chicken (Tables 5) is governed by energy content of the diet, productive state and nutritional adequacy (ICAR 2013).

Fats:

Fat is a concentrated source of energy, providing nine calories per gram, more than double the four calories per gram supplied by carbohydrates. In commercial poultry feeds, common sources of supplemental fat include animal fat, poultry fat, and yellow grease. The high cost of vegetable oils makes inclusion of these fats in poultry diets uneconomical. Fats are composed of smaller compounds called fatty acids. Fatty acids are responsible for cell membrane integrity and hormone synthesis. Fat is an essential component of poultry diets as it aids in the absorption of fat-soluble vitamins A, D, E, and K. Linoleic acid, an essential fatty acid for poultry, must be included in their feed. Beyond its nutritional value, fat is also added to reduce grain dust and enhance the palatability of the feed. However, fats in feed are prone to becoming rancid, so antioxidants are commonly added to preserve quality. One frequently used antioxidant in poultry diets is ethoxyquin.

Proteins:

Proteins are complex molecules composed of smaller units known as amino acids. During digestion, proteins are broken down into these amino acids, which are then used by the poultry to synthesize the specific proteins their bodies need. Proteins are used in the construction of body tissues such as muscles, nerves, cartilage, skin, feathers, beak. Egg white is also high in protein. Amino acids are typically divided into two categories, viz. essential and nonessential (Table 1). Essential amino acids are those that cannot be made in adequate amounts to meet the needs of the animal. The non-essential amino acids are those that the body can generate in sufficient quantities as long as the appropriate starting material is available. There are 20 amino acids commonly found in feed ingredients. Of these, 12 are essential and must be supplied in the feed. Poultry diets typically contain a variety of feedstuffs because no single ingredient is able to supply all the necessary amino acids in the right levels. Methionine and lysine are the two most essential amino acids for poultry. A deficiency in either can significantly reduce productivity and negatively impact flock health. Therefore, commercial poultry diets are supplemented with both methionine and lysine. The primary protein sources in poultry feed are plant-based, such as soybean meal, canola meal, and corn gluten meal. Animal-based proteins like fishmeal and meat and bone meal are also used. However, fishmeal must be limited to less than 5% of the total diet to avoid imparting a fishy taste to poultry meat and eggs.

Table 1. Requirement of Amino Acids:

Non-essential Essential Amino Acids	**Essential Amino Acids**	
	Critical	**Limiting**
Alanine	Lysine	Lysine
Aspartic acid	Methionine	Methionine
Glutamic acid	Methionine + Cystine	Threonine
Hydroxyproline	Tryptophan	
Proline	Threonine	
Glycine	Arginine	
Serine	Isoleucine	

Source: http://www.ndvsu.org/images/StudyMaterials/Nutrition/Poultrynutrition.pdf

Minerals:

Minerals are essential for bone formation and are involved in many vital functions such as blood cell production, blood clotting, enzyme activation, energy metabolism, and muscle function. They are generally categorized into macro-minerals and micro-minerals. Poultry need higher amounts of macro-minerals and smaller amounts of micro-minerals in their diets. The macro minerals include calcium, phosphorus, chlorine, magnesium, potassium, and sodium. Calcium plays an important role in blood clotting, bone formation, muscle contraction and eggshell quality (Tables 2, 3). Phosphorus is important for bone development, a part of cell membranes and is used for many metabolic functions. Chlorine required for the formation of hydrochloric acid in the stomach and thus plays a role in digestion. Sodium and potassium are electrolytes important for metabolic, muscle, and nerve functions. Magnesium also assists with metabolic and muscle functions. Micro-minerals, which include copper, iodine, iron, manganese, selenium, and zinc (as shown in Table 2), play vital roles in the body's metabolism. Iodine is essential for producing thyroid hormones that regulate energy metabolism, while zinc is important for many enzyme-driven processes. Iron is necessary for blood formation and oxygen transport throughout the body. Mineral requirements vary depending on factors such as the chicken’s breed, age, adaptation, production level, chemical form of the mineral, and interactions with other elements. Since grains are low in minerals, commercial poultry feeds are supplemented with minerals. Common calcium sources include limestone or oyster shell, while dicalcium phosphate provides both calcium and phosphorus. Micro-minerals are usually supplied through a mineral premix.

Table. 2. Nutrient Requirement for Broilers:

Nutrient	**Pre starter (0-3 W)**	**Starter (3–6 W)**	**Finisher (6–8 W)**
CP %	23.00	20.00	18.00
ME (Kcal/kg diet)	3200.00	3200.00	3200.00
Ly %	1.10	1.00	1.85
Meth %	0.50	0.38	0.32
Ca %	1.00	0.90	0.80
P %	0.45	0.35	0.30
Cu (mg/kg)	8.00	8.00	8.00
I (mg/kg)	0.35	0.35	0.35
Fe (mg/kg)	80.00	80.00	80.00
Mn (mg/kg)	60.00	60.00	60.00
Zn (mg/kg)	40.00	40.00	0.00
Se (mg/kg)	0.15	0.15	0.15
Vit. A (IU/Kg)	5000.00	5000.00	5000.00
Vit. D3 (IU/kg)	2400.00	2400.00	2400.00

Source: NRC (1994)

Table 3. Nutrient Requirement for Broilers:

Nutrient	Pre starter (0–14 d)	Starter (14–21 d)	Finisher (21–42 d)
CP %	22.00	21.50	19.50
ME (Kcal/kg diet)	3000.00	3050.00	3100.00
Ly %	1.20	1.07	0.94
Meth %	0.52	0.48	0.41
Ca %	1.00	0.95	0.85
Av. P %	0.45	0.40	0.38

Source: ICAR (2013)

Table 4. Nutrient Requirement for Broilers:

Nutrient	Pre starter (0–7 d)	Starter (8–21 d)	Finisher (21 d to market)
CP %	22.00	21.50	19.50
ME (Kcal/kg diet)	3000.00	3050.00	3100.00
Ly %	1.20	1.07	0.94
Meth %	0.52	0.48	0.41
Ca %	1.00	0.95	0.85
Av. P %	0.45	0.40	0.38

Source: BIS (2007)

Vitamins:

Vitamins are organic compounds needed in small amounts by poultry and are crucial for normal body functions, growth, and reproduction (see Table 2). They are classified into two groups: fat-soluble and water-soluble vitamins. The fat-soluble vitamins include A, D, E, and K. Vitamin A is particularly important for the proper growth and development of epithelial tissues such as skin and the linings of the digestive, reproductive, and respiratory systems as well as for reproduction. Vitamin D3 is required for normal growth, bone development, and eggshell formation. Vitamin K is essential for blood clotting. The water-soluble vitamins include vitamin C and the B vitamins. The B vitamins group includes thiamin, riboflavin, vitamin B12, biotin, folacin, niacin, pantothenic acid, and pyridoxine, all of which play key roles in metabolic processes. Poultry are capable of producing vitamin C naturally, so there is no established dietary requirement for it; however, supplementing vitamin C can be beneficial during periods of stress. A lack of these vitamins can result in various diseases or health problems.

Table 5. Nutrient Requirement for Layers:

Nutrient	Laying Pullets		
	0–8 wk	**8–16 wk**	**16–18 wk**
CP %	18.50	15.50	15.00
ME (Kcal/kg diet)	2600.00	2600.00	2700.00
Ly %	0.85	0.65	0.50
Meth %	0.32	0.29	0.27
Meth+Cysteine %	0.65	0.59	0.54
Threonine %	0.68	0.58	0.50
Linoleic acid %	1.00	0.80	0.80
Ca %	1.00	0.80	2.00
Av. P %	0.40	0.35	0.32
Na %	0.15	0.15	0.15
Cl %	0.15	0.12	0.12
Cu (mg/kg)	8.00	5.00	5.00
I (mg/kg)	0.35	0.35	0.35
Fe (mg/kg)	60.00	60.00	60.00
Mn (mg/kg)	50.00	40.00	40.00
Se (mg/kg)	0.15	0.10	0.10
Zn (mg/kg)	40.00	35.00	35.00
Vit. A (IU/kg)	3000.00	2500.00	3000.00
Vit. D3 (IU/kg)	300.00	250.00	300.00
Vit. E (IU/kg)	10.00	10.00	10.00
Vit. K (mg/kg)	0.50	0.50	0.50
Thiamine (mg/kg)	1.00	1.00	1.00
Riboflavin (mg/kg)	3.60	1.80	1.80
Pyradoxin (mg/kg)	3.00	3.00	3.00
Vit. B12 (mg/kg)	0.009	0.003	0.003
Biotin (mg/kg)	0.15	0.10	0.10
Folic acid (mg/kg)	0.55	0.25	0.25
Niacin (mg/kg)	25.00	11.00	11.00
Pantothenic acid	10.00	10.00	10.00
Choline (mg)	1300.00	900.00	500.00

Source: ICAR (2013).

Advances in Poultry Nutrition:

1. Determining Nutrient Requirements:

A significant challenge in determining nutrient requirements lies in their variability, as they are affected by numerous factors and continually evolve. These needs are primarily shaped by two categories: internal bird-related factors (such as genetics, sex, and the specific type and phase of production) and external influences (including temperature conditions, stress levels, and overall management practices). Achieving precision in determining nutrient requirements requires accuracy on both internal and external levels. Among all dietary components, essential amino acids and energy are the most costly and vital. Determining the requirements for the ten essential amino acids is quite complex, though this task has been simplified with the adoption of the ideal protein concept. As with other nutrients, amino acid needs are affected by factors such as genetics, sex, physiological condition, environment, and overall health. Nevertheless, most variations in amino acid requirements do not significantly alter the relative ratios among the different amino acids. Therefore, changes in amino acid requirements are typically represented in terms of a balanced or "ideal" protein profile. The ideal protein concept uses lysine as the benchmark amino acid, with the required levels of other essential amino acids expressed as a percentage or ratio relative to the lysine requirement. The benefit of this system is that once lysine requirements are established under various conditions, the requirements for all other essential amino acids can be derived accordingly. This method has become a widely accepted standard in the industry for determining amino acid specifications in feed formulation.

2. Determining Nutritional Composition and Feed Ingredient Quality:

The primary function of feed ingredients is to supply nutrients that birds can digest and use for growth and production. Over time, a vast amount of data has been collected on the nutrient composition of various raw materials. It is well recognized that each ingredient comes with inherent variability, which poses challenges for accurate feed formulation. To address this, data on nutrient variation often presented as matrices are available for key feed ingredients and are integrated into feed formulation systems to enhance precision. An important advancement in this area is the use of rapid testing methods, such as near infrared reflectance (NIR) analysis, which allow for quick estimation of overall nutrient composition and help monitor variability in ingredient quality over time. However, not all nutrients present in feed ingredients are fully available for productive use by birds; a portion remains undigested or unutilized and is excreted. With progress in feed evaluation methods, increasing amounts of data have become available on the bioavailability of nutrients particularly amino acids and phosphorus for poultry. A recent advancement in amino acid nutrition has been the broader adoption of digestible amino acid concentrations, instead of total amino acid levels, for use in feed formulation (Ravindran *et al.*, 2005). Using digestible amino acids in feed formulation is particularly important when including ingredients with low digestibility. This strategy allows for greater use of alternative feedstuffs, improves formulation precision, lowers costs, and supports consistent bird performance. Energy measurement is also key due to its impact on productivity and cost. While metabolizable energy (ME) is the standard, the net energy (NE) system—though theoretically more accurate—remains underutilized. Limited data and the complexity, cost, and time involved in NE measurement hinder its routine use, despite its potential to better predict poultry performance.

3. Improved Feed Formulation:

After establishing the nutritional requirements, the next step is to meet these needs by selecting suitable combinations of ingredients and supplements. The goal of formulation is to create a balanced diet that supplies the necessary amounts of available nutrients at the lowest possible cost. Due to the wide variety of potential ingredients and nutrients, numerous complex calculations are required to develop a cost-effective diet. Over time, feed formulation has progressed from manually balancing a few feedstuffs and nutrients to using computer-based linear programming systems. Nowadays, newer stochastic nonlinear programming systems are gaining popularity as commercial formulation software becomes more accessible. Since ingredient composition varies in a nonlinear way, stochastic programs effectively manage this variability in the most cost-efficient manner. Additionally, growth models are increasingly used to simulate feed intake and production outcomes based on specific husbandry conditions. Such models are effective tools to (i) compare actual versus potential performance, which can indicate the extent of management or health problems in the flock, and (ii) provide economic analysis of alternative feeding regimens. It must be noted, however, the models are only as good as the datasets used to develop them.

4. Application of Biotechnology-based Additives in Poultry Nutrition:

Over the past twenty years, advances in biotechnology have created new possibilities to boost animal productivity and efficiency by enhancing nutrition. Biotechnology encompasses a wide range of applications within the field of animal nutrition. Some of these applications are already in use (Table 1) as distinct from others whose potentialities are known but are yet to be commercially applied because of technical limitations and public concerns (Table 2). The widespread adoption of feed additives in poultry production over the past twenty years has been remarkable. Among these, in-feed antibiotics have been the most effective and widely used additive in the industry, contributing significantly to the current level of performance efficiency. The ban on in-feed antibiotics, due to concerns about human antibiotic resistance, presents a major challenge. While alternatives are being investigated, they have not yet been widely adopted commercially. Exogenous enzymes, however, have become a well-established tool in poultry nutrition. Introduced in the 1990s, enzymes like xylanases and glucanases effectively reduce the negative effects of non-starch polysaccharides, enabling greater use of viscous grains such as wheat and barley in poultry diets. Over the last decade, the use of microbial phytase has also increased in poultry diets, driven by concerns about phosphorus pollution from waste generated by intensive animal farming (Selle and Ravindran, 2007). More recently, carbohydrase enzymes like xylanases, amylases, and glucanases, along with other exogenous enzymes such as proteases, are becoming increasingly important commercially. Blends of these enzymes have proven effective even in maize-based diets (Cowieson, 2010), which naturally contain low levels of non-starch polysaccharides (NSP). Another significant advancement is the availability of crystalline amino acids, which allows nutritionists to more precisely match the ideal amino acid profile, thereby enhancing the performance and yield of high-producing modern poultry.

Table 1. Examples of Some Biotechnological Applications that are widely used in Poultry Nutrition:

Application	Aim(s) of Developing the Technology
1. New ingredients	Production of microbial proteins as new feed sources in animal feeding (e.g. single cell protein, yeast protein).
2. Designer ingredients	Nutritional enhancement (e.g. high-oil maize, high-methionine lupins) or reduction in the level of anti-nutritive components in common feed ingredients (e.g. low-phytate maize).
3. Feed additives	
a) Antimicrobials	To suppress the growth of harmful bacteria and promote the establishment of a desirable gut flora balance (e.g. antibiotics)
b) Crystalline amino acids	To increase dietary supply of specific amino acid and improve protein balance in diet formulations
c) Feed enzymes	To improve availability of nutrients (energy, amino acids, phosphorus etc) in feed ingredients by reducing the negative effects of anti-nutritive components (e.g.

	microbial phytases acting on phytate, reducing the negative effects of anti-nutritive components (e.g. microbial phytases acting on phytate, xylanases acting on arabinoxylans in wheat).
d) Nutraceuticals	To provide protection against chronic, infectious and non- infectious diseases
4. Gut ecosystem enhancers	
a) Probiotics	To promote the establishment of a desirable gut ecosystem through the proliferation of beneficial species (e.g. direct-fed microbials)
b) Prebiotics	To competitively exclude harmful organisms and promote the establishment of a desirable gut ecosystem (e.g. mannan oligosaccharides)
c) Synbiotics	To enhance capacity of prebiotics and probiotics
d) Organic acids	To manipulate intestinal microbial population and improve immune response
5. Feed supplements	
a) Nano-minerals	To enhance bioavailability of minerals.
6. Toxin binders	To reduce toxicity of aflatoxins.
7. Antioxidants	To check ill effect of free-radicals

Table 2. Examples of Some Biotechnological Applications with Future Potential in Poultry Nutrition:

Application	Aim(s) of developing the technology
1. Modification of gut microbes	To genetically modify microorganisms naturally present in the gut to enhance their capacity for defined functions or add new functions (e.g. rumen microbes to improve cellulose digestion)
2. Introduction of new gut microbes	To introduce new species or strains of microorganisms into the gut

3. Bioactive peptides	Improved growth and efficiency (e.g. growth hormone-releasing peptides), improved gut function, immunomodulation, antibacterial properties
4. Antimicrobial replacers	Antimicrobial enzymes (e.g. lysozyme), delivery of specific antibodies via spray-dried plasma and egg products
5. Transgenesis	To modify nutrient metabolism and improve growth efficiency by transfer of genes

5. Processing of Feed:

Advancements in feed manufacturing technology over the past 50 years have been essential for enhancing poultry performance. The process has evolved from simple mash mixing to pelleting, which incorporates a range of physical, chemical, and thermal treatments (Schofield, 2005). Today, most broiler feed is provided in pelleted or crumbled form. Feeding poultry with pellets or crumbles has improved production efficiency by boosting feed conversion and growth rates. These benefits are largely due to reduced feed wastage, increased nutrient density, minimized selective feeding, less time and energy spent on eating, elimination of harmful pathogens, and thermal changes to starch and protein (Amerah *et al*., 2007).

6. Phase Feeding:

Phase-feeding, a type of precision feeding, has emerged over the last two decades. It involves gradually lowering dietary amino acid levels over time to reduce expenses linked to surplus protein or amino acids. In commercial poultry production, phase-feeding programs may include multiple stages for adjusting amino acids and other nutrients in broiler and layer diets. The number of feeding phases used depends on both cost-effectiveness and practical implementation. The broader adoption of phase or precision feeding is hindered by several challenges. These include the need for continuously updated data on ingredient variability and matrix values, as well as more comprehensive information on digestible amino acid content in key raw materials. Additionally, there is a lack of comparative data on amino acid digestibility across different poultry types and ages especially since nutrient and energy digestibility is lower in the first week of life. There are also significant gaps in knowledge regarding metabolizable energy and digestible amino acid requirements for various poultry classes. Lastly, the absence of rapid, reliable tests to assess metabolizable energy and digestible amino acids at feed mills limits practical implementation.

Poultry nutrition is essential for achieving optimal growth and productivity, with faster growth translating to greater profitability for poultry industry. Over the years, advancements in poultry nutrition have played a significant role in boosting production. As the global population continues to rise rapidly, the importance of nutrition in sustaining progress within the poultry industry has become even more critical. These advancements are largely driven by sophisticated techniques developed and refined by researchers across both academic and industrial sectors. It is important to strike a balance between fundamental research, which offers long-term value, and applied research that provides immediate, practical solutions. Looking ahead, achieving future nutritional goals will require a strong interdisciplinary approach from scientists.

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Chapter-11

Nutritional Strategies for the Prevention of Metabolic Disorders in Animals

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Introduction:

Dairy animals (especially high producing) suffer from various metabolic disorders. Therefore, balanced diet is very important for dairy animal's Diet/ ration deficient/ imbalanced in various nutrient viz. proteins, energy, minerals and vitamins or any disturbances in the proper ratio of various nutrients as well as improper ratio of roughage to concentrate may develop various nutrition related metabolic disorders in dairy animals. High producing dairy animals are able to produce huge amount of milk. In attempt to consume, digest and metabolize enough nutrients to satisfy lactation needs, those animals are exposed to serious stress conditions that can affect their health.

Metabolic disorders in dairy animals (cows and buffaloes) are a key problem especially in the transition period and often appear before the onset of further health problems. Problems derive from difficulties animals have to adapt to large variations and disturbances occurring both outside and inside the body. A lack of success in solving these issues may be due to predominant traditional feeding practices and approaches in farm management and animal husbandry practices, dealing with such disorders as merely negative side effects. Instead, a successful adaptation of animals to their living conditions should be seen as an important end in itself. Both farm management and scientific feeding practices and their metabolic adaptation should support animals in their ability to cope with these metabolic challenges by employing scientific adequate nutritional strategies in priority basis as functional and result-driven approach. Metabolic adaptation is a functional and target-oriented process involving the whole animals' body and thus cannot be narrowed down to single factors. Most problems which challenge the animals can be solved in a number of different ways. To understand the mechanisms of metabolic adaptation, the interconnectedness of variables and the nutrient flow within a metabolic network need to be considered.

Metabolic disorders indicate an overstressed ability to balance input, partitioning and output variables. Dairy animals will more easily succeed in adapting and in avoiding dysfunctional processes in the transition period when the gap between nutrient and energy demands and their supply is restricted. Dairy farms vary widely in relation to the living conditions of the animals. The complexity of nutritional and metabolic processes and their large variations on various scales contradict any attempts to predict the outcome of animals' adaptation in a farm specific situation. Any attempts to reduce the prevalence of metabolic disorders should rely on continuous and comprehensive monitoring with appropriate nutritional strategies on the farm level.

Metabolic disorders of animals are a group of diseases that affect animals immediately after calving. A number of disorders linked to incorrect diet or feeding can have adverse effects on animal health and welfare, as well as productivity. Health disorders are associated with significant economic losses for dairy farms due to reductions in milk production, increased risk of culling and death, increased treatment cost and reduced reproductive performance. There are several metabolic disorders identified in dairy animals. Metabolic diseases have a great economic impact. The losses are as a result of decreased milk production, decreased efficiency of milk production, premature culling, veterinarian costs, reduced fertility and death in serious cases. Financial losses occur due to metabolic disorders especially ruminal acidosis and ketosis was Rs. 19368.30 and 78211.04, respectively as direct cost per animal.

Nutrition plays an important role in preventing metabolic disorders pre and post calving and through lactation. Metabolic disorders can invariably be prevented by ensuring the best possible dietary and particularly careful management of animals at drying off, during the dry period and in early lactation. This is known as the transition period. A close relationship between NEB and fertility disorders has been exist in animals. Increased locomotive problems are also associated with longer and more extreme periods of negative energy balance. As a consequence, individual production diseases of the dairy cow should not be considered in isolation. For example, ketosis, fatty liver, retained placenta, hypocalcaemia, metritis, and displaced abomasum may be all interrelated. Primary causes and the confounding factors which contribute to the development of metabolic disorders are manifold and vary considerably between farms.

The transition period, defined as the period between three weeks before to three weeks after parturition, is the most challenging and critical period in relation to the dairy animal's health status during the lactation cycle. Major physiological, nutritional, metabolic, and immunological changes occur within this time frame as the production cycle of the cows and buffaloes shifts from a gestational non-lactating state to the onset of copious milk synthesis and secretion. Dairy animals must adjust metabolically to the dramatic increase in energy and nutrient requirements needed to ensure milk production in the ensuing lactation. Gaps between nutrient demand and supply in the first weeks of the transition period can coincide with substantial variations in the diets' nutrient content and in the daily dry matter intake

(DMI), requiring comprehensive adaptation and regulation of the metabolism. Disturbances of one or multiple metabolic processes, related to the regulation of a certain metabolite in the body fluids, are known as metabolic disorders, and are a manifestation of the dairy animal's inability to cope with metabolic demands.

Metabolic disorders most related to nutritional management are ketosis, milk fever, retained placenta, metritis, displaced abomasum, and lameness. The colloquial associations among various metabolic stresses and their relationships to other diseases, particular infectious and inflammatory diseases of early lactation are interrelated and have become a central focus of the interest in metabolic disorders of dairy animals.

Three terms are basically very-2 important for understanding the metabolic disorders in dairy animals' i.e. metabolic load, metabolic stress and allostasis. Metabolic load was defined as the burden imposed by the synthesis and secretion of milk, whereas metabolic stress was defined as that amount of metabolic load which cannot be sustained, such that some energetic processes, including those that maintain general health, must be down regulated. Though, the allostasis refers to changing regulatory systems (stability through change). It can be considered as the process of maximizing fitness in the face of environmental change as well as unpredictable challenges. Regulatory mechanisms must change in order to maintain or achieve a state appropriate for the time of day or year and in response to disturbances.

In early lactation, animals are in a stage of negative energy balance (NEB) caused by a rapid increase in the demand for nutrients to support milk production which exceed the increase in food intake. This results in lower blood glucose and mobilization of body reserves to provide additional energy. These processes are accompanied by elevated blood concentrations of non-esterified fatty acids (NEFA) and ß-hydroxybutyrate (BHBA) and decreased levels of calcium and phosphorus. Many health disorders in dairy animals are attributed to the process of uncontrolled lipid mobilization in response to excessive NEB in early lactation. All of these metabolic changes increase the risk for ketosis, hepatic lipidosis, hypocalcemia, and infectious diseases, such as mastitis and metritis.

Nutritional Strategies to Prevent Metabolic Disorders:

Increasing the proportion of good quality roughage (hay or forages) in the diet, and decreasing the starch intake (i.e. cereal grains such as corn, wheat, or barley) reduce the incidence of sub-acute rumen acidosis. By increasing the proportion of roughage in the diet, the time of chewing and the amount of saliva produced will be increased. Feeding direct-fed microbial or probiotics that utilize glucose or lactate. It can also be prevented by balancing the diet for starch and effective fibre; avoid sudden feed changes; feed buffers such as sodium bicarbonate or ionophores such as Rumensin.

Feeding diets rich in highly fermentable carbohydrates that induce an acidic state has been identified as one of the key factors in pathogenesis of laminitis. Digestive disorders such as acidosis, changes in the gastrointestinal bacterial flora, and translocation of endotoxin into the bloodstream predisposes high producing dairy animals to laminitis. Adding buffers to diets may help maintain claw integrity as buffers, such as Na-bicarbonate, minimize the drop in rumen pH. Supplements that contain combinations of complex trace minerals Zn, Mn, Cu and Co positively influence claw health, and it has been advised to feed them when lameness is problem in a herd.

In dairy animals, ketosis is a lactation disorder usually associated with intense milk production and negative energy balance (NEB). It occurs at the stage of lactation and hence can be extremely costly affair. It is closely related to diet and farm management. It is a major metabolic disorder of dairy animals in early lactation, which develops when dairy animals fall into a condition of excessively NEB caused by insufficient dietary intake leads to high concentrations of ketone bodies and low concentration of glucose in the blood. A concentration of serum BHBA greater than 1200-1400 µmol/L is a common standard used for the diagnosis of ketosis.

Ketosis can be prevented by supplementation of balanced ration, particularly energy intake; maximise dry matter intake before, at and after calving. Avoid over-fat dairy animals at calving (BCS>6 out of 8), lower potassium and calcium levels in the dry animals. They can also give niacin as it may be effective if fed at 6 grams per day, feed monensin in the last month of pregnancy. Daily use of sodium propionate (0.25 lb./lactating animal) after calving is identified to be preventive against ketosis in dairy animals. Treated animal with sodium propionate not only increase blood sugar levels and lower blood ketone bodies in their blood, but also have higher milk production.

Oral propylene glycol administration is found to be effective in preventing ketosis in dairy animals and also to be efficient for make obvious increase in milk production. Animals treated with 300 ml oral propylene glycol daily produced 0.23kg more milk per milking in the first 30 d of lactation. Propylene glycol can be administered as a drench. The traditional does is 225g twice daily for 2 days, followed by 110g daily for 2 days to cattle, but higher volumes are also used. Propylene glycol (200-700g daily), or salts of propionic acid, can be administered in the feed and give good results. Propylene glycol most likely reduces fatty acid mobilization from adipose tissue and by this mechanism can be protective against ketosis and fatty liver syndrome.

Animal fed a mixture of conjugated linoleic acid (CLA) isomers in a Ca-salt form from day 13 through 80 postpartum. The CLA supplementation on cow performance during day 14 through 28 post-calving; however, milk yield was increased, and percentage and yield of milk fat were decreased, during day 35 through 80 postpartum. Energy balance was not affected by treatment during either period. In addition to nutritional strategies used to decrease the supply of circulating NEFA available for extraction by the liver, the potential exists to employ nutritional strategies to decrease the rate at which NEFA are converted to triglycerides within the liver.

Choline is a quasi-vitamin that has a variety of functions in mammalian metabolism. Its most significant functions are as a component of the predominant phospholipids contained in the membranes of all cells in the body (phosphatidyl choline), a component of the neurotransmitter acetylcholine, and as the direct precursor to betaine in methyl metabolism. Most of the potential application of choline within transition animal nutrition has focused on its role in lipid metabolism because phosphatidylcholine is required for synthesis and release of VLDL by liver. Feeding choline in rumen-protected form to transition dairy cows tended to decrease the rate of accumulation of esterified products in liver slices *in vitro*, implying that VLDL export was sensitive to choline supply also in dairy cows.

Methionine (Met) and Lysine (Lys) are frequently considered to be the two most limiting amino acids (AA) for synthesis of milk and milk protein. These two AAs also have potential roles in mitochondrial Β-oxidation of fatty acids (carnitine biosynthesis) in liver and export of triglycerides as VLDL. A potential role for Met in bovine ketosis has been speculated for more than 30 years. Investigators that have sought to increase the supply of Met as either rumen-protected Met or its analog (2-hydroxy-4-(methylthio)-butanoic acid) beginning prior to parturition and continuing through early lactation generally reported increased milk yield during early lactation.

Dry period is a management strategy that reduces the magnitude of NEB after calving and triglyceride accumulation in the liver and can be protective against metabolic diseases related to imbalanced energy levels like ketosis. Monensin treatment significantly reduced the incidence of subclinical ketosis.

Milk fever/parturient paresis/ hypocalcemia is one of the most frequent metabolic disorders of economic importance, in high yielding dairy animals. Dairy animals suffering from milk fever becomes susceptible to secondary disorders, which also adds significantly to production cost. Feed a transition diet three weeks to calving, include anionic salts; avoid feeds high in potassium, sodium and calcium in the diet; increase dietary calcium immediately after calving; avoid fat cows at calving; administer vitamin D injections 2–8 days before calving for cows with a history of milk fever.

Oral ca drenching around calving apparently has a mean efficacy of 50%–60% in terms of milk fever prevention. Feeding rations with a negative dietary cation-anion difference (DCAD) significantly reduce the milk fever incidence. The principle of feeding rations low in calcium is highly efficient in milk fever prevention provided the calcium intake in the dry period is kept below 20 g per day. Large doses of vitamin D metabolites and analogues for milk fever prevention. Oral administration of easily absorbed calcium supplement nearer around calving to prevent the occurrence of milk fever. The feeding of acidifying rations by anionic salt supplementation during the last weeks of pregnancy. Feeding low calcium rations during the last weeks of pregnancy.

Supplementation/ administration of vitamin D, vitamin D metabolites and analogues one week before calving prevent milk fever. Anionic diets help maintain blood Ca at parturition and prevent milk fever when fed to cows during the last several weeks of pregnancy. Feeding an anionic diet before parturition has been advised if the incidence of milk fever in a herd exceeds 10%, and also when it is desired to improve the health status and production in herds in which MF is not a serious problem.

Fatty liver is a metabolic disorder characterized by a high content of lipids and triglycerides in the liver. The disease occurs in peri-parturient period, primarily in the first 4 weeks after calving, and as a secondary disease of other production diseases that depress appetite or increase body fat mobilization. All nutritional measures that prevent drop in DMI before parturition may be useful in prevention of fatty liver. However, it has been assumed that increased energy and nutrient density of the diet may assure maintenance of the same intake of nutrients and energy despite lower DMI around calving, and decrease rate of lipid mobilization. Increase in nutrient density during the last 2–3 weeks prepartum by increasing concentrates in the ration has been referred to as steaming-up or close-up diet.

Displaced abomasum is a multi-factorial disorder where the abomasum is dilated as a result of gas accumulation and dislocated to the left (left-displaced abomasum) or to the right (right- displaced abomasum) in the stomach in relation to the normal placing. The passage of feed to the intestines is partly or totally blocked. Approximately 80-90% of the incidences are left-displaced abomasums. The disease is most frequent in high producing dairy animals in early lactation and 80–90% of the cases are seen in the first 4 weeks postpartum. Nutrition has been implicated as a major risk factor in the etiology of displaced abomasums. Low feed intake and increased NEB prepartum have been found to increase the risk of displaced abomasums in lactating cows and buffaloes.

Animals fed high concentrate diets in early lactation or diets with inadequate particle size are also at increased risk of displaced abomasums. Sudden changes in the diet and rapid increase in concentrate allowance in early lactation are also the risk factors. Low intake of concentrates during the prepartum period also may increase the risk of left displaced abomasum because absorptive capacity of the ruminal papillae is not increased sufficiently and microbial population of the rumen is not adapted prior to intake of high energy postpartum diets.

Clinical hypomagnesaemia in animal with plasma Mg concentrations bellow 0.4 mmol/L is manifested as grass tetany. Large number of factors influences the development of the disease. Older animals also have reduced ability to mobilize body reserves of Mg. However, periods of rapid plant growth during any season, resulting in forage of low Mg and high moisture, high nitrogen (N) and K, present dietary conditions that increase the potential for the development of tetany.

Feeding program had little if any effect on udder edema. Addition of Na or K to the diet before calving can increase the incidence and severity of udder edema in dairy cows and first calf heifers. High level of NaCl or KCl in the feed during the dry period may be one of the major factors in the development of udder edema around calving.

Dietary supplementation of vitamin E or Se may improve antioxidant status and decrease the incidence of those diseases. The similar effects can be obtained by addition of beta-carotene in the diet. Dietary supplementation of beta-carotene can elevate blood beta-carotene and enhance peripartum host defense mechanisms by enhancing lymphocyte and phagocyte function. Dietary supplementation of calcium can prevent hypocalcaemia during and after parturition and less chances of retention of placenta (ROP). Feeding TMR only once or twice a day may result in that cows eat an excessive amount of feed during a short period of time, because animals are strongly attracted by the arrival of fresh food.

Conclusion:

Understanding the metabolic adaptations that dairy animals make as they transition from a non-lactating to lactating state has enabled continual development of specific nutritional strategies to control/ prevent these metabolic disorders. Efforts to improve the energy status of dairy animals during the peri-parturient period and decrease NEFA release from adipose tissue by feeding added dietary fat sources or trans-10, cis-12 CLA have not resulted in improved metabolism or consistently improved performance. Choline and essential fatty acids may increase rates of hepatic export of NEFA as triglycerides in VLDL. Calcium mobilization in support of lactation can be facilitated effectively by lowering the DCAD of the diet fed during the prepartum period; however, the degree to which the DCAD must be lowered to sufficiently alleviate hypocalcaemia. Feed a ration balanced for protein, energy, fiber, vitamins and minerals. Dairy animals according to production and adjust body condition accordingly during lactation.

Dry animals off at a 3.5 body condition score, the desired score for the dry period and at calving. Maintain this condition throughout the dry period, avoiding the fat cow syndrome and related metabolic disorders. Provide exercise for dry animals. Maintain a balance of forage-to-concentrate in the total mixed ration after calving to maximize intake but to prevent digestive upsets (ketosis, acidosis, DAs) during adaptation to the peak lactation ration. Feed grass hay, or pasture to dry animals to minimize calcium intake to prevent milk fever. Limit corn silage fed to dry cows to approximately 30-40 pounds daily and feed approximately 10 pounds of grass hay or equivalent forage. Limit concentrate feeding after peak lactation and conception have occurred. Maintain a 12- to 13-month calving interval to avoid long dry periods by providing good health and nutrition measures and expert reproductive practices.

Chapter-12

Gastrointestinal Functionality and Health: An Emerging Way for Sustainable Animal Production

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Introduction:

The gastrointestinal tract (GIT) enables efficient breakdown of feed into absorbable nutrients through motility, enzymatic secretion, and microbial activity. The GIT is considered the largest organ of the immune system, with more than 70% of immune system cells residing there (Vighi *et al.,* 2008). Gut health is foundational to overall well-being, affecting digestion, immunity, mental health, metabolism, and disease prevention. Maintaining a balanced gut microbiome through a healthy diet, stress management, and lifestyle choices is essential for sustaining both physical and mental health. A healthy gut is characterized by effective digestion and absorption of nutrients, a stable and diverse microbiome, minimal digestive symptoms, and the absence of gastrointestinal diseases or complaints that would require medical attention. Each segment of the digestive tract must have a secure barrier to keep microbes contained within it. A strong barrier can be considered a sign of good gut health. When the barrier is compromised, microbes or pathogens may escape the digestive tract and enter the body or bloodstream, potentially leading to various diseases. Stress can weaken the digestive tract barrier, which negatively impacts the gut barrier system and allows pathogens to invade. Effective gastrointestinal functionality is becoming increasingly important in animal nutrition and health, where it plays a key role in profitable and sustainable production. By optimizing digestive efficiency, enhancing immune responses, and reducing environmental impacts, gut health strategies are reshaping modern livestock management practices.

Key Components of Gut Health:

Diet: Diet influences the growth of beneficial microbes, modulates the immune system, produces antimicrobial peptides, modulates cytokine production, and regulates intestinal barrier function. A gut-friendly diet can lower levels of fermentable proteins in the hind gut. It possesses the least buffering capacity and insignificant content of anti-nutritional factors. The inclusion of feed additives and other beneficial compounds helps to prepare a gut-friendly diet.

Gut Mucosa: The GIT acts as a barrier composed of a mucus layer overlying intestinal epithelial cells and an underlying set of gut-associated lymphoid tissue (GALT). All of these barriers interact with functional entities of the body to maintain healthy gut integrity by counteracting the pathogens. The Gut-associated lymphoid tissue (GALT) is a system of lymphoid tissues that comprises the gut immune system.

Gut Microflora: The intestinal microbiome is home to trillions of microorganisms representing hundreds of different species. Impairment of the GIT microbiome, impacts, often negatively, the functionality of the host's local defense system.

Functions of Gut Microbiota:

Gut microbes are vital for animal health by providing defense, supporting gut structure and immunity, and aiding in digestion and nutrient absorption.

Protective Functions: Gut microbes help protect the host by:

- Displacing pathogens, thereby preventing harmful microbes from colonizing the gut.
- Competing with pathogens for nutrients, limiting the resources available for harmful organisms.
- Competing for receptor sites on the gut lining, which blocks pathogen attachment.
- Producing antimicrobial factors that directly inhibit or kill harmful microbes.

Structural Functions: Gut microbes contribute to the physical and immune integrity of the gut by:

- Fortifying the gastrointestinal tract (GIT) barrier, making it harder for pathogens to penetrate.
- Inducing the production of Immunoglobulin A (IgA), an important antibody for mucosal immunity.
- Tightening the junctions between gut epithelial cells, which reduces gut permeability and prevents leakage of harmful substances.
- Supporting the development of the host's immune system.

Metabolic Functions: Gut microbes play essential roles in metabolism by:

- Fermenting non-digestible dietary residues, which helps extract additional nutrients and energy from food.
- Synthesizing vitamins that the host cannot produce on its own.
- Controlling the differentiation of intestinal epithelial cells, which is important for gut health and function.
- Assisting in the absorption of ions, contributing to the host's mineral balance.

Health Benefits of Gut Microbes:

- Gut microbes stimulate the goblet cells in the intestine. These goblet cells then produce mucus. The mucus forms a layer that acts as a physical barrier, protecting the intestinal lining from harmful substances and pathogens.

- Gut microbes trigger the intestinal epithelial cells. In response, these cells produce tight junction proteins. The production of tight junction proteins helps maintain the integrity of the GIT by keeping the cells closely connected and preventing harmful substances from leaking through the gut lining.
- The gut microbiota favors the production of lactate, which leads to a reduction in the pH levels within the hindgut, making the environment more acidic. The lowered pH in the hindgut creates conditions that inhibit the growth of harmful bacteria, likely promoting a healthier microbial environment.
- The gut microbiota is responsible for the activation of Gut-associated lymphoid tissue (GALT), which is part of the immune system associated with the gut and plays a role in detecting and responding to pathogens. GALT activates or interacts with Mucosal-associated lymphoid tissue (MALT), a broader network of lymphoid tissues associated with mucosal surfaces like the gut, respiratory tract, etc. This process leads to the production of antibodies, which are essential for targeting and neutralizing harmful pathogens, thereby protecting the body from infections.
- The gut microbiota plays an important role in breaking down food and absorbing essential nutrients, critical for maintaining energy and health. They are essential for maintaining the integrity of the gut lining, which serves as a protective barrier against harmful substances and pathogens.
- Gut microbiota contributes to the maturation and regulation of the immune system, aiding the body in defending against infections. They limit the growth of harmful microorganisms by competing for nutrients and space, and contribute collectively to maintaining gut and overall health.

Sustainable Animal Diets:

Sustainable animal diets are feeding strategies for livestock that balance nutritional adequacy, animal health, environmental responsibility, and economic viability. These diets are designed to provide all essential nutrients for optimal animal growth, health, and productivity, to avoid harmful or deleterious components, and to support production objectives while ensuring that animal products are safe for human consumption. These animal diets must contribute to economic sustainability and profitability in agricultural practices and ensure the protection of the environment and the natural resource base. The sustainable animal diets must be prepared in a socio-culturally acceptable and beneficial way. For preparing sustainable animal diets a number of functional foods or nutraceuticals can be incorporated in animal diets which are described as follows.

Functional Foods/ Nutraceuticals for Improving Gut Health:

1. **Probiotics:** Probiotics are live microorganisms that, when administered in adequate amounts, confer health benefits on animals. Probiotics are generally Gram-positive bacteria from the genera Bacillus, Enterococcus, Lactobacillus, Pediococcus, and Streptococcus, as well as some fungi and yeast strains like Saccharomyces cerevisiae and Kluyveromyces species. Probiotics are found in two primary forms: a dry powder form, prepared using lyophilization technology that employs freeze-drying to preserve the probiotics in a dry state. In this form, probiotics are encapsulated to ensure they remain effective and viable for long-term storage. The other form is liquid, which is fed directly as a broth medium containing 24–48-hour live cultures.
2. **Yeast-Derived Supplements:** Yeast-derived dietary supplements are increasingly used as pre- and probiotics to enhance gut health. Yeast cells release beneficial compounds that engage in oxygen scavenging, creating an anaerobic environment conducive to microbial growth. They also generate high-potency vitamins, enzymes, and minerals, which enhance the nutritional environment. In the rumen, yeast-derived supplements stimulate the growth and activity of bacteria, help maintain an optimal pH for microbial activities, and increase bacterial numbers and functions, nurturing a healthy microbial ecosystem made up of bacteria, fungi, and protozoans. These beneficial compounds exhibit antibacterial activity in the intestine, inhibiting the growth of pathogenic bacteria such as E. coli. The overall advantages of yeast-derived gut microbiota include an increase in beneficial microbial flora, improved gastrointestinal microbial balance, enhanced gut health, better overall animal health, and improved production performance, such as increased milk yield or growth rates.
3. **Prebiotics:** Prebiotics are selectively digestible feed ingredients that promote the growth of beneficial microbes by providing necessary substrates. Examples include mannan oligosaccharides (MOS), fructose oligosaccharides (FOS), and galactose oligosaccharides (GOS). Approximately 90% of oligosaccharides escape digestion and reach the colon, where they selectively stimulate the activity of gut microflora. Prebiotics encourage fermentation, leading to the production of lactic acid by beneficial bacteria. This lactic acid production lowers the pH in the hindgut, creating an acidic environment. Such conditions promote the growth of Lactobacillus species, which are beneficial bacteria known for their health-promoting properties. The increase in Lactobacillus spp. and the acidic environment drives a significant shift in the composition of gut microbiota,

favoring beneficial microorganisms over harmful ones. Additionally, prebiotics enhance the production of mucin, a protective gel-like substance secreted by intestinal epithelial cells. Mucin plays a critical role in forming a barrier that safeguards the intestinal lining from pathogens and physical damage. Prebiotics prevent the growth of harmful bacteria through two methods: either by directly binding to pathogenic bacteria, inhibiting their ability to colonize and cause infections, or by increasing the intestinal lumen's osmotic value, which creates an unfavorable environment for the survival and growth of pathogens by altering osmotic conditions within the gut lumen. These mechanisms underscore the importance of prebiotics in promoting balanced and healthy intestinal microbiota while protecting against pathogenic bacteria.

4. **Potentiated Probiotics and Synbiotics:** The term potentiated probiotics refer to such combinations of probiotics with other additives (e.g., vaccines or organic acids) to synergistically increase the effect of the probiotic. The most common pairing that has been tested is prebiotics with probiotics, and this combination is termed synbiotics. Lee*,* (2009) studied the effect of synbiotics on growth, digestibility of nutrients, emission of harmful gases, and composition of intestinal microbiota of 150 pigs during the weaning period. The study reported that the supplementation with the synbiotic product resulted in improved digestion of nutrients, reduced emission of harmful gases, and prevents bacterial infections during the weaning period.
5. **Direct-fed Microbials (DFM):** One alternative to optimize the digestibility of complex carbohydrates is the inclusion of dietary enzyme supplements. Bacillus spp. that produced cellulose and xylanase enzymes were used as DFM and were found to reduce digesta viscosity and reduce C. perfringens growth in different diets containing complex carbohydrates (Latorre *et al.,* 2015).
6. **Organic Acids:** Organic acids can be inherent or added, and they function by decreasing the pH of an environment, limiting feed spoilage, and resulting in lower pathogen survival in the gut.
7. **Acidifiers:** The acidifiers enhance nutrient absorption in the intestine, create an acidic environment that is unfavorable for pathogenic bacteria, help maintain a healthy microbial balance in the gut, allow for better digestion and nutrient breakdown, stimulate pancreatic secretion resulting in improved enzymatic digestion, supports the growth of beneficial microorganisms, enhances efficiency in converting feed to energy, facilitates the uptake of essential minerals. Acidifiers also contribute to better nutrient digestibility, leading to improved health and growth. Also, increases the production of fatty Acids and antioxidant capacity and enhances the body's ability to fight infections. Ultimately, acidifiers

contribute to improved productive and reproductive performances, ensuring better growth rates, healthier animals, and higher yields.

8. **Polyphenols:** Polyphenols belong to a class of phytochemicals that include secondary plant metabolites, catechin, tannin, and chlorogenic acids, which are the typical components of animal diets. They play a potential role in modulating gut health by exerting antioxidant and anti-inflammatory properties. Polyphenols help in maintaining the intact epithelial barrier function to prevent disruptions that could lead to infections or diseases. They also balance gut microbiota for optimal digestive and immune functions and prevent the entry of harmful bacteria or their substrates into the circulation. In addition, they stabilize the cell membranes against reactive oxygen, indicating a protective effect against oxidative stress, which can damage cells and lead to inflammation or other health issues.
9. **Antioxidants:** Antioxidants are routinely supplemented in livestock's diet to counteract the negative impact of excessive ROS production and to improve their health and productivity. Dietary antioxidants are necessary not only to sustain animal health and performance but also to guarantee high quality of their products (Chauhan *et al*., 2014).
10. **Dietary Fibers:** Dietary fibers play a crucial role in the complex interaction between the key components for optimal gastrointestinal functionality (Jha and Berrocoso, 2016). Stimulation of microbial fermentation is a desirable outcome as it is accompanied by an increase in short-chain fatty acids, which results in a decrease in intestinal pH (Den Besten *et al.,* 2013).
11. **Feed Enzymes:** Feed enzymes improve animal performance by hydrolysing feed substrates that are only partially or not broken down by the animal's endogenous enzymes (Ravindran, 2013). Exogenous enzymes have been proposed as possible alternatives to antibiotic growth promoters as they can produce nutrient substrates for specific populations of bacteria through their action (Cheng *et al.,* 2014). Feed enzymes improve the stability of the gut by reducing substrate for putrefactive organisms, increasing substrate for beneficial fermentative organisms, and enhancing the ability of the intestine to defend itself against unwanted bacterial ingress.
12. **Vaccines:** Vaccines are an underappreciated antibiotic alternative despite the availability of many effective vaccines and a general understanding of vaccine immunology. As an example, vaccination against the swine pathogen Lawsonia intracellularis reduced the need for therapeutic oxytetracycline administration in Danish pigs (Bak and Rathkjen 2009).

Conclusion:

Gut health plays a crucial role in maintaining well-being of animals thus in turn enhancing animal production. Proper functionality and integrity of gut to maintained with the help of slight modifications in animal diets to balance the gut microbiota. By employing measures which improves the gut health and at the same time contributes to sustainable animal production can be used as effective way to promote animal health.

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