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ANIMAL HEALTH AND NUTRITION EVOLVING TRENDS AND FUTURE OUTLOOK

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

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Rajasthan University of Veterinary and Animal Sciences (RAJUVAS) Bikaner

Animal Health and Nutrition: Evolving Trends and Future Outlook

Editors: R.K. Dhuria, Deepika Dhuria, Jagriti Srivastav, Shahji Phand and Sushrirekha Das

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This e-book is a compilation of resource text obtained from various subject experts of Rajasthan University of Veterinary and Animal Sciences, Bikaner and MANAGE, Hyderabad, Telangana on "Animal Health and Nutrition: Innovative Strategies and Future Outlook" conducted from 24th – 26th September, 2024. This e-book is designed to educate extension workers, students, research scholars, and academicians related to veterinary science and animal husbandry about the innovative techniques and recent trends in the area of Animal Nutrition and Health which can support the Animal Husbandry Practices by enhancing Animal production as well as by improving Animal health.

Published for Dr. Sagar Hanuman Singh, Director General, National Institute of Agricultural Extension Management (MANAGE), Hyderabad, India by Dr. Srinivasacharyulu Attaluri, Deputy Director, MANAGE and printed at MANAGE, Hyderabad as e-publication.

Vice-Chancellor
Rajasthan University of Veterinary and Animal Sciences
Bijay Bhawan, Near Pt. Deen Dayal Upadhyay Circle
Bikaner-334001 (Rajasthan)
Email: vcrajuvas@gmail.com

Prof. Manoj Dixit

FOREWORD

Rajasthan University of Veterinary and Animal Sciences (RAJUVAS), Bikaner is marching ahead to provide technical and scientific support for transforming state animal husbandry from sustainability to improved profitability. Improved production in association with productivity spurt has led the state to be one of the leaders in the country for milk, meat and wool production with the support of scientific and technological interventions and favorable policy environment. The University is envisaged to take up teaching, research and extension programmes in the field of Veterinary and Animal Sciences.

Proper nutrition promotes good health in livestock, which results in higher productivity. By providing animals with the necessary nutrients, one can enhance their overall health, reduce the risk of diseases, and improve their growth and productivity. To obtain optimum productivity the role of animal nutrition on growth, health, production and reproduction should be known to everyone related with the livestock activity. Organization of trainings on this aspect is the need of the day. I am happy and express my sincere thanks to 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 proving platform to organize this training program at RAJUVAS, Bikaner.

The compilation of different lectures delivered during the training program on "**Animal Health and Nutrition: Innovative Approaches and Future Outcome**" organized by RAJUVAS, Bikaner and MANAGE, Hyderabad from 24th to 26th September 2024 in the form of present E-book will serve as a guide and reading material for students and researchers in the field of Animal Health and Nutrition. I am confident enough that this E-book will help the readers in updating their knowledge about various innovative technologies for improving livestock productivity.

I appreciate the efforts made by Prof. R.K. Dhuria, Course Director and Dean, PGS, RAJUVAS, Bikaner and his whole team for taking the initiative for this productive learning experience and to publish this E-book. I wish all success to the participants and faculty.

(Prof. Manoj Dixit)
Vice-chancellor

Dean, Post Graduate Studies
Rajasthan University of Veterinary and Animal Sciences
Bijay Bhawan, Near Pt. Deen Dayal Upadhyay Circle
Bikaner-334001 (Rajasthan)
Email: dhuriark12@gmail.com

Prof. (Dr.) R.K. Dhuria

PREFACE

Animal feeds play a leading role in the global food industry, enabling the economic production of animal products worldwide. The feed sector is critical in supporting animal's optimal health with high resilience capabilities to stressors through safe and high-quality feed and access to nutritional innovation. Therefore, it is a key factor in the well-being of all livestock species. Animal nutrition has a pronounced direct impact not only on animal health but also indirectly through animal products on human health. There is a need to apply research-based ideas and innovative technologies in the field of animal nutrition to enhance the production potential of animals and to keep them healthy as well. Incorporating advanced scientific nutritional approaches into the traditional animal feeding system can increase the efficiency of animal production and reduce the environmental impact associated with it. Looking to the importance of animal nutrition on animal health there is need of the day to acquaint the students, researchers, scientist working in this field about innovative concepts and emerging technologies to improve animal productivity.

The E-book **"Animal Health and Nutrition: Evolving Trends and Future Outlook"** aims to provide knowledge about recent innovations in the field of Animal Health and Nutrition which can contribute directly for improving Animal Production. An attempt has also been made to cover all the aspects of technologies being used in the field of Animal Nutrition presently and their future scenario as well as practical significance in the livestock feed industry. We hope that this E-book will be beneficial to acquaint the readers with emerging concepts of animal nutrition in the present scenario along with the point of the future outlook

I would like to express 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 also acknowledge other editors of this E-book Dr. Deepika Dhuria, Dr. Jagriti Srivastav, Dr. Shahji Sambhaji Phand and Dr. Sushrirekha Das. I am thankful towards National Institute of Agricultural Extension Management (MANAGE), Hyderabad for generously supporting the training program and for publishing this E-book.

(R.K. Dhuria)
Dean, PGS

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Chapter-1

Assessment of Animal Feed Safety and Quality in India

Dinesh Bhosale
GM, AB Vista South Asia, Pune
Email: dtbhosale@gmail.com

Feed - Food Safety Programme:

Safe food begins with safe feed. Maintaining high quality and nutritional value throughout the feed to food chain is vital to supporting optimal animal performance and preventing risks to human health. As the world population continues to rise, driving increased demand for animal protein, we are sharpening our focus on producing high quality feed with limited resources. Trouw Nutrition India supports raw material producers, traders, feed mills, integrators and farmers in achieving the highest possible level of feed safety and quality by: preventing nutritional losses in raw materials, supporting maximum efficiencies in feed production, and using food by-products as valuable feed ingredients.

Feed Processing and Quality Programme:

Efficient and safe feed production is the foundation of any poultry and livestock production system. Spoilage and pathogenic microorganisms, such as *Salmonella*, *E.coli*, fungi and yeast, can negatively impact feed quality and nutritional value. On the other hand, effective moisture management can positively impact feed processing efficiency and throughput. Through our feed processing and quality programme, we offer feed processors and integrators total solutions by partnering up to find the most efficient ways to maintain feed quality, extend its shelf-life and improve feed mill efficiency.

Process Moisture Management:

Managing feed's moisture profile is essential at the feed mill, in transport and during storage. Various processes and conditions that occur during feed manufacturing can adversely affect feed quality and producers' economics. Organic acid blends are a useful tool to optimize feed manufacturing efficiency and feed integrity and support feed hygiene. Friction during grinding that takes place in the manufacturing process generates heat, which leads to moisture loss. This can result in lost weight of the feed produced and a sub-optimal pellet. Introducing a hydrating solution comprised of water mixed with blends of surfactants and organic acids into the mixing process can improve the wetting and absorptive properties of the feed. Specific surfactants allow moisture to be distributed more evenly throughout the ingredients, which allows for better binding and cooking in the conditioner. The surfactants' binding abilities also optimize starch gelatinization and reduce moisture loss from the feed. Optimizing feed mill efficiency can increase not only moisture levels in feed, but also improve feed mill profitability.

Feed Hygiene:

Pathogenic microbes, such as *Salmonella* and *E.coli*, not only affect the nutritional quality of feed but may also lead to reduced animal performance. Measuring risk is an important step in safeguarding feed safety. By analyzing raw material and feed samples, you can ensure the most effective solution is applied. Trouw Nutrition offers solutions through buffered blends of organic acids that can help safeguard microbiological risks after feed leaves the mill and protect against recontamination risk across the distribution chain. The buffering of organic acids is essential to ensure the solution evaporates less and has a longer period of efficacy. As hygiene enhancers, organic acids also provide a good alternative to formaldehyde, which has been banned in the EU for several years.

Mycotoxin Risk Management Programme:

Mycotoxin risk management Contamination of raw materials with mycotoxins in the field or during storage at feed mills is a significant challenge in maintaining the quality of final feed. Failure to achieve high quality of feed can mean economic losses for feed millers as a result of poor feed prices, diminished brand image and compromised performance of animals. Mycotoxins produced by moulds are a growing problem in feed production. Trouw Nutrition's integrated Mycotoxin risk management programme enables feed producers to make data-based decisions and use mycotoxin control solutions more precisely to address this issue. This programme is proven to reduce overall mycotoxin risk by a 3D approach: Risk identification, quality control and application of solutions.

Global Mycotoxin Review 2023–2024:

In this webinar recording, we explore insights from over 65,000 mycotoxin analyses conducted in 2023, offering invaluable strategies for effective risk management in 2024. Dr. Swamy Haladi, Selko's Global Technical Commercial Manager, provides global-level guidance on navigating this extensive dataset. Joining him is Mr. Avinash Bhat, Technical Specialist at Masterlab, offering innovative perspectives on interpreting and forecasting the data. Gain expert insights to optimize mycotoxin risk management for your operations.

Identifying the Risks:

To help identify the risk of mycotoxins in feed on the farm, Trouw Nutrition offers Mycomaster, a lateral-flow smart device that provides a reliable quantitative reading of the contamination levels in feed materials and compound feed. It enables rapid on-site, cost-effective and user-friendly analysis of six different mycotoxins: Zearalenone, Deoxynivalenol, Aflatoxins, Fumonisins, Ochratoxin and T2-HT2. This easy-to-use tool gives results within 15-30 minutes, which means that feed producers can analyse mycotoxins themselves. It can also be connected to Trouw Nutrition's global data exchange system, allowing the review of data collected from all over the globe.

Ensuring Proper Quality Control:

Since mycotoxins are produced by moulds, it is important that raw materials and feed are stored properly at feed mill or farm level. Quality control is key: new materials should be tested upon arrival to detect contamination levels and even reject raw materials if mycotoxin levels are exceeding guidance values. Proper hygiene measures are also crucial on the farm to prevent mould and mycotoxin development at a later stage. For example, regular cleaning of feed troughs will prevent residue feed from getting mouldy. Pay special attention to silage, which can be prone to mould growth due to the favorable conditions during storage. Finally, animal performance should be monitored closely, to detect any symptoms of increased mycotoxin levels.

"Constant exposure to mycotoxins may lead to chronic toxicity and economic losses. A comprehensive mycotoxin risk management programme should be in place to prevent and reduce such economic losses."

Swamy Haladi, DVM., PhD, Global Programme Manager Mycotoxin Risk Management

Powerful Solutions:

Once raw material or feed quality have been assessed and the mycotoxin levels identified, you may need to take actions to prevent mycotoxins from affecting animal health and performance. Trouw Nutrition's TOXO products provide a complete solution against a broad spectrum of mycotoxins, combining four main modes of actions, designed to support animal health and performance during mycotoxin exposure.

1. Effective absorption ability through smectite-based bentonite clays has been proven by numerous *in vivo* and *in vitro* validation studies. These ingredients do not bind to other valuable nutrients in feed.
2. Support for gut integrity through specific glucose biopolymers, reinforcing enterocyte tight junction protein complexes, which are damaged by inflammation during mycotoxin exposure.
3. Immune system modulation through highly purified Beta glucans, which act as immune modulating agents with proven *in vivo* and *in vivo* efficacy.
4. Anti-oxidative support through specific antioxidants and vitamins that promote the metabolism of mycotoxins in the liver.
5. India's regulatory bodies keep on conducting nationwide surveillance in its ongoing effort to curb adulteration and ensure the safety of animal-origin products. These bodies coordinate with the industry association to amend the present regulations or bring new ones to the industry. Think Grain Think Feed

interacted with Suresh Deora, Chairman of CLFMA of India to understand such changes and what is the way forward.

6. Present Status of Feed Safety Infrastructure: The Bureau of Indian Standards (BIS) is a regulatory body that grants licenses on receipt of an application, but the enforcement of the compulsory BIS Certificate is done by the authorities notified for quality control orders, the Food Safety and Standards Authority of India (FSSAI) being one such authority for food products and recent intervention has been done in feed products also.
7. On October 6, 2021, FSSAI issued a directive specifying that all commercial feeds intended for meat and milk-producing animals must comply with the BIS specifications (Indian Standard, IS 2052: 2009- Compounded Feeds for Cattle – Specifications, 4th revision) and shall carry the BIS mark. But it has not yet been implemented. Though BIS has already granted 124 licenses to manufacturers for the use of the BIS standard mark on
8. Compounded Feeds for Cattle as per Indian Standards IS 2052: 2009. Almost 50 feed manufacturing companies, mostly big players, are registered with BIS. This is minuscule compared to the size of the industry. As more feed manufacturing companies start adopting the regulations, the lab infrastructure also needs to be further developed.
9. There is a lack of National Accreditation Board for Testing and Calibration Laboratories (NABL)-accredited food & feed testing labs. The centre for Analysis and Learning in Livestock & Food (CALF) at NDDB Anand is one of the most prominent multidisciplinary analytical laboratories in the country. The facility tests feed samples from across the country, and recently VERKA also set up such infrastructure. Still, there is a long way to go. Many smaller players, especially in mash feed manufacturing, do not follow any product identification or other quality parameters.
10. States such as Andhra Pradesh, Kerala, and Odisha have Livestock Feed acts under which law enforcement is done to ensure the quality of packaged animal feed and the expiry date printed on the packets. Other states and UTs should also be adopting it to ensure safe feed and hence safe animal food production.
11. Is BIS Certification Transferable? As of now, there is no clarification on whether a company already registered with BIS would need to apply for further registration

if the FSSAI regulation is implemented or how the company should proceed in the case of multiple species feed manufacturing.

12. Role of Regulations in Mitigating Aflatoxin**:** Aflatoxin is a huge concern for the poultry and livestock industries. Especially in the case of animal nutrition, almost 70-80% consists of fodder, which is not regulated and highly susceptible to alflatoxin development because of favorable climatic conditions in India. Hence, without fodder quality assurance, there would be hardly any change in the dairy industry.
13. DDGS: E20 fuel, the government aims to blend 20% ethanol with petrol by 2025 where corn will be a major ingredient. This will bring more DDGS (a by-product) and might challenge the availability of corn in the feed sector. Regular intervention is needed to get the desired quality of DDGS for the animal feed industry which otherwise can be another huge concern.
14. Initiatives from the New Chairman**:** As the chairman of the esteemed association, I am planning to implement the following:

    1. Run for protein
    2. Segregation of feed millers depending upon their major interest in any species
    3. Establish a pilot feed mill with the ministry to train young staff

    (https://benisonmedia.com/feed-fodder-safety-way-forward-for-india/)

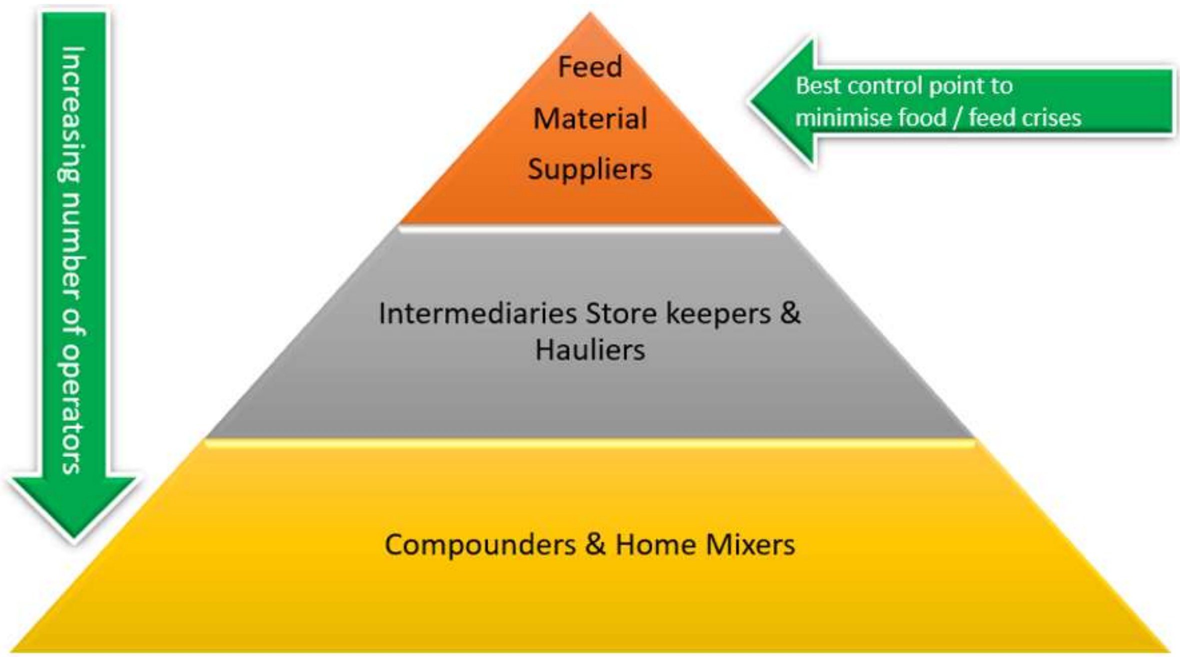
Risk Management along the Feed Chain:

Assuring feed safety is everybody's business and requires special attention at the early stages of the feed chain, based on FEFAC's "top-of-the-pyramid" principle, seeking to identify and minimize hazards at the beginning of the feed chain. The FEFAC Vision on Feed Safety is based on three pillars: capacity building, optimization of risk management along the chain and cooperation with authorities.

Feed safety crises in the past have shown how vulnerable the livestock sector can be in case of shortcomings at early stages of the feed supply chain. Competition for resources, the increased focus on (food) waste reduction and climate change are all factors requiring focused attention by risk managers to maintain the integrity of the feed chain. This makes it clear that the responsibility to safeguard feed safety is shared between all actors of the feed chain, benefitting from close cooperation between feed business operators and feed safety assurance systems including an open dialogue and information exchange with competent control authorities.

FEFAC calls for a risk-based approach towards feed safety at each stage of the feed supply chain where it is most efficient, based on its "top of the pyramid" approach. Feed-related EU RASFF notifications show that the large majority of feed safety incidents have their origins at the beginning of the supply chain. The FEFAC Vision on Feed Safety Management invites feed ingredient suppliers to increase their involvement in the management of risks. Compound feed and premix manufacturers rely on their suppliers to proactively share information about feed ingredient risk profiles and safety data sheets that could facilitate the feed safety management at the level of compound feed production.

The credibility of the systems put in place by the feed chain partners has resulted in significant improvement. Almost 2/3 of the feed-related EU RASFF notifications are generated by controls performed by feed business operators themselves. The structured dialogue and cooperation between control authorities and operators, as laid down in the new EU Official feed and food control regulation 2017/625/EC, will further strengthen the efficacy and complementarity of official and private controls, through risk-based feed safety management measures. Both feed chain partners and official control authorities share the same key objective, preventing feed safety incidents to safeguard animal health & welfare as well as Public Health.



External Links:

Other sectoral Guides to Good Hygiene Practices in the feed sector

Relevant Documents:

- FEFAC Vision on Feed Safety Management ((15) PR 4)
- Cooperation between industry associations and national authorities ((15) PR 16)
- Common set of principles for Salmonella risk management ((10) PR 10)
- Community guide to good practice for the EU industrial compound feed and premixtures manufacturing sector for food-producing animals - EFMC version 1.2

Emerging Feed Resources:

Research & Innovation is continuously offering emerging or underused feed resources (former foodstuffs, insects, algae, single cell protein, processed animal proteins), which may make a contribution for the sustainable development of the EU feed & livestock chain. Their potential use does require a comprehensive risk assessment, covering animal health, human health and the environment to ensure their safe use in the feed chain.

The increasing global demand for food of animal origin and the development of new processing technology for non-feed/food uses for crops, provides a strong incentive for feed manufacturers to test alternative feed resources which have not (yet) been fully explored. This includes a wide product range including former foodstuffs, algae, insects and a larger variety of other co-products from different food and non-food industries, contributing to the circular economy.

A key prerequisite for any potential feed use of such products is the establishment of detailed risk profiles. FEFAC recommends to all chain partners and research institutes to carry out comprehensive risk assessments to ensure that the safety status can be guaranteed at each stage of the chain. National Risk Assessments bodies and EFSA can play a very important role in the process of establishing the risk profiles of these emerging or alternative feed resources, as was the case in 2015 for the safety of insects as animal feed.

Circular economy practices are going to be promoted across the feed and food chain (and non-food sectors like renewable energies) and this requires a review of certain restrictions currently in place. Some potential feed resources have indeed been subject to legal prohibitions at a certain point in time, due to unmanageable risks. This was the case of certain Processed Animal Proteins whose use in food producing animals was banned in 2001 in the wake of the BSE crisis.

Some of these restrictions were decided at a time when technology, traceability and auto-control capabilities were not yet at the level of efficiency and accuracy which they reached in the meantime. The re-authorization of non-ruminant PAPs in fish feed in 2013 and the re-authorization of porcine PAPs in poultry feed and vice versa in 2021 was approved at EU level after a thorough risk assessment and evaluation of the efficiency of improved risk management tools.

However, there are still a number of restrictions on the use of certain materials in feed for food producing animals: catering reflux, ruminant PAPs or nutrients such as phosphorous recovered from urban waste waters, which are prohibited in accordance with Annex III of EU Regulation 767/2009 on the Marketing of Feed. Like in the case of avian and porcine PAPs, there may be certain cases where regulatory restrictions may no longer be risk-proportionate and necessary to guarantee a high level of feed and food safety. FEFAC is therefore in favour of a pro-active re-evaluation of the need to maintain these restrictions provided a number of conditions are met:

- An updated in-depth risk assessment by EFSA;
- Responsibility and commitment of operators to preserve feed safety & product integrity, in particular via the development and implementation of transparent feed safety assurance schemes;
- Strict supervision by competent control authorities with ad-hoc control tools (fitness for purpose of analytical means);
- Social acceptance issues (intra-species recycling, ethical concerns);
- Proportionate risk management measures regarding conditions of use.

Relevant Documents:

- Circular Feed – Optimised Nutrient Recovery Through Animal Nutrition (June 2022)
- Questions & Answers on the Partial Lifting of the Feed Ban (2021)
- FEFAC position on the re-authorisation of non-ruminant PAP in non-ruminant feed (2021)
- FEFAC technical impact assessment of the re-authorisation of pig PAPs in poultry feed (2019)
- Proceedings of the FEFAC – ASSALZOO workshop on New protein sources – How to secure effective risk analysis (2015)

Feed Additives:

Feed additives are essential constituents of a feed for the technological, sensory, nutritional or zootechnical function they exert. A modernization of the EU legal framework is urgently required to assist the feed and livestock sector to further improve its sustainability.

Feed additives are in many aspects intrinsic constituents of a compound feed. They contribute to optimized use of resources by facilitating homogeneity of the mixture (e.g. emulsifiers), the density and durability of a pellet (binders) or preserving fatty material or vitamins from oxidation (antioxidants). They can also stimulate the appetite of animals (flavourings) or balance the diet in essential nutrients like vitamins, amino acids and trace-elements. The zootechnical additives like microorganisms facilitate digestion and contribute to reduce emissions in the environment. Advances in animal nutrition sciences have identified many new applications for feed additives including new promising functionalities which support animal welfare and the physiological status of animals to help them cope with pathogens, thus reducing the need for the use of antibiotics at farm level.

Feed additives, whose producers are represented among others by FEFANA, EMFEMA, IMA-Europe or Animal Health Europe, are subject to pre-authorization further to submission of an application by an operator of the feed chain, often the feed additive supplier, alone or in consortia. The applicant must in particular demonstrate that the product is safe for the species which the feed additive is intended to, for the consumer of the animal products, for the operator handling the substance and for the environment. In addition, the applicant must also provide evidence of the ability of the substance to fulfil its function, what is called in regulatory jargon the efficacy. The authorizations are delivered for a period of 10 years, subject to renewal.

The current EU Feed additive Regulation (EC) No 1831/2003 has now reached its limits and requires a serious REFIT to ensure that it can deliver on some of the key objectives set out in the EU Farm to Fork communication (Climate change & AMR reduction & Nutrient management). FEFAC has highlighted the following key challenges in the REFIT consultation on EU Regulation (EC) No 1831/2003:

- How to secure authorization of generic feed additives, in particular technological and nutritional feed additives? The situation is critical for minor uses and for certain functional groups such as antioxidants with only a few substances left.

- How to stimulate innovation in areas of high political importance such as reduction of the needs for antimicrobial treatment, animal welfare or reduction of environment emissions? No single feed additive has yet been authorised for these functions, due in particular to the unpredictable outcome of the evaluation process.
- How to reduce dependency on third countries for the supply of feed additives? The EU remains highly dependent on third countries for the supply of certain essential feed additives, in particular vitamins.

External Links:

DG SANTE webpage on the REFIT of feed additives legislation

Relevant Documents:

- FEFAC COMMENTS TO THE COMBINED EVALUATION ROADMAP/ INCEPTION IMPACT ASSESSMENT FOR THE REVISION OF THE FEED ADDITIVES REGULATION (EC) No 1831/2003
- FEFAC comments on the EU Commission roadmap for the REFIT of the feed additives legislation ((17) PR 26)

Feed Safety Standards:

Managing feed safety starts first with a good knowledge of what is safe and what is not and how to prevent/minimise/control. For that, operators can rely on a combination of legal and professional sectorial standards.

Hazards in feed may be of chemical (heavy metals, dioxins, mycotoxins, pesticide residues, etc.), biological (Salmonella, TSE agent, viruses) or physical nature (metal, glass, etc.). Securing feed safety requires assessing the risk that, whenever contaminants are present in a feed, they are present at levels that are safe for the animal eating them and do not adversely impact on the animal welfare and performance. In addition, the risk that such hazards are transferred into food of animal origin (accumulation in meat, fat or kidneys, transfer into milk or eggs) at levels unsafe for consumers must also be assessed. Finally, the risk for the environment is also taken into consideration.

Such risk assessments require specific knowledge and skills which can be provided by public authorities and their risk assessment bodies, which make significant contributions to the setting of legal standards, most of the time via maximum limits, which are established based on an EFSA risk assessment.

Maximum limits for chemicals are set in two major pieces of EU legislation, i.e. the EU Directive on Undesirable Substances and Products (Directive 2002/32/EC) and in the EU Regulation on Pesticides MRLs (Regulation (EC) No 396/2005). In addition, guidance values are established for certain mycotoxins with no or negligible transfer into animal products leading to negligible exposure of consumers (Commission Recommendation 2006/576).

Microbiological criteria are set for Salmonella and Enterobacteriaceae in feed materials of animal origin only (Regulation (EC) 142/2011). Standards for feed materials from vegetable origin is a non-EU harmonized area, meaning it is left to national authorities to define appropriate targets in terms of microbial contamination of feed.

As regards physical hazards, the EU Regulation (EC) No 767/2009 prohibits the presence of packaging residues in feed.

The EU RASFF is widely used as an indicator to identify the risk-exposure ranking of the different types of contaminants:

- 3 out of 4 notifications concern microbial contamination; however the absence of a harmonised EU standard limits its analytical value;
- Heavy metals, ragweed, non-authorised chemicals and ruminant DNA represent between 6 and 12 notifications per year;
- Non-compliance with MRLs for pesticides and dioxins represent 4 to 6 notifications per year. Non-EU-authorised GMOs are detected occasionally (0 to 2 notifications per year).

FEFAC strongly supports the establishment of harmonised EU standards for contaminants in feed whenever this is justified, based on occurrence data and risk assessment by EFSA. FEFAC is collecting data from its member companies on contamination of feed materials and sharing these data with EFSA or DG SANTE, as relevant.

FEFAC continues requesting additional risk management focus on the prevention of contamination at an early stage of the chain (e.g. prevention of mycotoxins at farm level), in line with its “top-of-the-pyramid approach”. Indeed, once a contaminant is present, the feed manufacturer has only very limited risk-mitigation options.

FEFAC requested the establishment of specific pesticide MRLs for products destined exclusively for feed use, in the context of the REFIT consultation. Such harmonized standards are essential to ensure the proper functioning of the single market.

FEFAC calls also for harmonization of standards for the management of the Salmonella risk at EU level. Meanwhile, FEFAC, together with other partners of the chain, have defined common principles for the management of Salmonella risk along the chain (toolbox).

FEFAC, as an observer member of CODEX, contributed in partnership with its International Feed Industry Federation, to the drafting of a Guidance document on prioritizing hazards in feed and Guidelines on the application of risk assessment for feed, based on an FAO report on hazards associated with feed safety.

Relevant documents

- EFMC version 1.2 (2014)
- FEFAC report on RASFF notifications in 2019 ((20) INFO 1

Why is Feed Safety Important?

Animal feed plays a leading role in the global food industry and it is the largest and most important component to ensure the sustainable production of safe and affordable animal proteins. Rapidly growing populations, along with increased urbanization and income, is expected to rise the consumption of animal products by 70% in 2050. The increase in animal production will require an additional amount of feed to be produced. The challenge is not only to meet the growing demand for feed, but to ensure its safety.

Feed safety is a prerequisite for food safety and human health, as well as a necessity for animal health and welfare. It is a component of access to trade, income generation and economic sustainability. In addition, it contributes to feed and food security and decreases feed losses. In fact, feed is an integral part of the food chain and its safety has been recognized as a shared value and a shared responsibility. Feed production must thus be subject, in a similar manner as food production, to the quality assurance of integrated food safety systems.

The role of animal feed in the production of safe food is recognized worldwide, and several critical incidents have underlined its impact on public and animal health, feed and food trade, and food security. For instance, the following are all related to animal feeding: Bovine Spongiform Encephalopathy; Foot-and-Mouth Disease; dioxin, mycotoxin, E. coli O157:H7 contaminations; and the development of antimicrobial resistance. Work on the application of the risk analysis framework provided by Codex in the field of animal feeding has facilitated the further understanding of the role of animal feed safety on public health and of the importance of risk-based measures to prevent and control hazards. Hazards may be introduced with source materials or via carryover or contamination of products during handling, storage and transportation.

In many countries adequate know-how and sufficient awareness are lacking to ensure feed safety among all operators along the whole value chain. Even where more knowledge is available and control systems are in place, new and unconventional feed ingredients are entering the production chain e.g. agro-industrial by-products (such as the ones of the biofuel industry), insects, food processing by-products, food wastes, etc., and with them, possibly new safety risks. Moreover, many countries still lack feed regulatory frameworks and fail to implement feed regulations harmonized with the Codex Alimentarius and other international standards.

https://www.fao.org/feed-safety/background/why-feed-safety/en/

Feed Safety Documentation:

We define feed safety as protecting animals and the people that feed them from illness or injury from handling or consuming our feed products. We strive to continuously improve feed safety.

Feed Safety Letters & Audit Certificates:

Document Request:

Feed safety is an important issue for Cargill and will continue to increase in importance for the company. It is fundamental to our success. We define feed safety as protecting animals and the people that feed them - at every step in the supply chain, from production to consumption - from illness or injury from handling or consuming our feed products. We strive to continuously improve feed safety.

Our Core Operating Principles:

Leadership: Producing the safest food/feed possible is absolutely critical to the ongoing success of our business. We strive to be a reliable source of our customers; have the trust of regulators; earn the confidence of consumers; and are a catalyst to improve food/feed safety in the industries which we operate.

Transparency: Cargill works with others across the public and private sectors to address safety issues in the food/feed supply and to establish common expectations and policy principles to improve the overall supply chain.

Personal Responsibility: At Cargill, we believe all employees are responsible for contributing to the success of our food/feed safety systems. We empower them to bring forward ideas that could improve our efforts and to take action when they see a problem in our operations that may compromise food/feed safety.

Accountability: We hold ourselves accountable to fully implement our food/feed safety approach and continuously seek ways to improve the food/feed safety systems. Cargill continually monitors each of our facilities, and acts swiftly to address any food/feed safety issue within our supply chain. We are committed to continuous improvement in the area of food/feed safety through ongoing research and new food/feed technologies and interventions.

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4. Food Safety Modernization Act (FSMA)
5. FDA website
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Chapter-2

Gut Health: An Emerging Concept for Improving Animal Nutrition and Productivity

L. C. Chaudhary and Anju Kala
Animal Nutrition Division, ICAR-IVRI, Izatnagar
Email: lcchaudhary1@rediffmail.com

The gastrointestinal functionality and its health are important for sustainable animal production. It can be defined as the absence of diseases in human medicine. This may not be true ruminant production as the efficiency of animals might be affected without showing any apparent signs of diseases. The digestive tract needs to have a secured barrier to keep microbes inside the tract. A good barrier can be referred to as good gut health. When the barrier is weak, microbes or pathogens can exit the digestive tract and enter into the body and may cause diseases (Eckel, *et al.,* 2016, Mountzouris and Brouklogiannis, 2024). The ruminants have very well-developed rumen microbial ecosystem, which is characterized by presence of large variety of microbial consortium. The bacteria are most abundant microorganisms (10^{10}-10^{11}/ml) followed by protozoa (10^5-10^6/ml). The fungi are less abundant (10^3-10^4/ml). The methanogenic archaea and phases are also present in the rumen. The microbial consortium of a healthy rumen normally depends on the type of diet given to animals. The manipulation of rumen microbial ecosystem for desired rumen fermentation to improved livestock production have been one of the very important researchable area for last several decades throughout the globe and to some extent success has been achieved in this direction. However, progress is slowed due to incomplete information on rumen microbial ecosystem especially of uncultivable rumen micro-biota, which constitutes about 85-95% of total population (Kamra, 2005). In present communication an attempt has been made to compile the information on gut health specially on rumen microbes and their possible interactions to improve, gut health, rumen metabolism and livestock production under Indian condition.

Factors affecting Gut Health:

All the factors which have a direct or indirect effect on the gastrointestinal physiology affect the gut health of an animal. Therefore, to understand the gut health functionality it is important to understand the interactions among the following:

Diet: Diet is the important factor which has bearing on the functionality of the gut health. The composition of the diet, nutrients present and additives mixed, have the capability to alter the functioning of the digestive system, the immunity of the animal and also the micro biota. Thus, in order to maintain good gut health, the farm nutrition and diet needs to be optimized.

Digestion and Absorption of Nutrients*:* The better digestion and absorption of nutrients are very important processes of the GIT and has positive influence on the animal gut health. The presence of pathogens causing intestinal inflammation or those which lead to an increase in the defensive response of the body should be avoided at all costs.

Gastro-intestinal Tract Microbial Population: The gastro intestinal tract microbial population is an important factor to several metabolic, structural and protective processes of the animals. They help to keep the gut healthy and safe.

Gut Mucosa: The inside monolayer of epithelium of the intestinal tract is covered by a mucosal layer secreted by the epithelial layer along with its underlying mesenchyme and dendritic cells and lymphocytes and macrophages. This mucus layer has a protective function and prevents the gut liming from getting harmed by the diet and nutrition consumed by the animal.

Welfare: The other important external factors like poor hygiene, horse climatic factors, dense stocking rates, etc., also have negative effect on the gut health of the livestock.

Immunity: If the body immunity of the animals is compromised, all physiological functions of the the animals will be affected adversely. To avoid this situation, care should be taken that the animal's diet properly balanced.

Importance of the Rumen Microflora:

The rumen of adult ruminants consists of dense and diverse microflora, whereas the rumen in young born calves has simple microbes. The rumen is inoculated with the dam, diet ingestion, and contact with the environments and gradually colonized by a large number of diverse microbes that affect the epithelial cell function and gut-associated lymphoid tissue development (Jami *et al*., 2013). The ruminal microbes contain bacteria (Firmicutes and Bacteroidetes as the 2 predominant phyla), archaea (such as *Methanobrevibacter smithii* and *Methanosphaera stadtmanae*), fungi and protozoa, among which bacteria are the most predominant and diverse. The researchers reported that the immune responses could be affected the activation or suppression of Toll-like receptor caused by microbial signals in humans and perhaps the same may happen with ruminants and rumen microbes are essential for the development and regulation of the neonates' immune system and play a key role in maintaining life-long health and high productivity. Compared with the reticulum, omasum, and abomasum, the adult rumen plays important role in degradation of feeds. Rumen microbes can ferment carbohydrates to VFA, which contribute 80% of the energy required by ruminants. Some rumen microbes also synthesize their own proteins for growth utilizing the energy and nitrogen of feed. The microbes are digested in the small intestine and absorbed by the host, thereby contributing to host's nutrition and health. Microbes also produce vitamins, like vitamins B and K.

Dietary Manipulation of Rumen Microbiota to Improve Ruminant Livestock Production:

Diet is a major cause of changes in the rumen microbial composition. Roughage based diet results in a higher abundance of bacterial order Bacteroidales and family Ruminococcaceae, whereas a grain-based diet results in a higher abundance of genus Prevotella and family Succinivibrionaceae, regardless of the ruminant species. The effect of rumen microbes on production of ruminants has mainly been explained using the dietary manipulation-based studies that influence microbial composition. Dietary manipulation in ruminants is aiming to improve the rumen microbial fermentation either via enhancing beneficial metabolic processes or minimizing inefficient/harmful metabolic processes. The researchers have tried several strategies to manipulate the rumen ecosystems to improve rumen functions for increasing the production efficiency of the animals. The major areas of the rumen function modification are as follows:

- Controlling acidosis in the rumen:
- Feed toxin degradation
- Improving fibre digestibility
- Improving tannin rich feed utilization
- Reducing methane production
- Altering livestock product

Interactions between Rumen Microbes and Feeds:

The interesting facts of the rumen function are the interrelationships or association patterns between the various microbes and also with the feed given. In many cases, effects of food type on the animal's health and the efficiency of animal performance can be traced back to the effects of these interactions on function of rumen.

The rumen microbes, although different in phylogeny, are intrinsically related and their symbiotic relationship is key to rumen function, especially fibre digestion. Bacteria, protozoa and fungi colonize and degrade the indigestible lignocellulose and, in that process, they release hydrogen which is utilized by archaea and generates methane (Janssen and Kirs, 2008). Each microbe has its preferred substrate and changes in the diet make changes in the rumen microbial population.

Most of the bacteria associated with food particles, either firmly attached or loosely attached. These attached bacteria are grouped in micro-colonies, which are groups of symbiotic bacteria growing near each other apparently to facilitate the transfer of nutrients between their cells. The remaining 20-40% is found free in the rumen liquor (liquid associated). Other bacteria (about 1%) are found attached to the rumen epithelium where they are involved in the hydrolysis of urea as it diffuses back into the rumen and in scavenging oxygen and others are attached to protozoa and fungal sporangia. Bacteria are either generalists or specialists in their use of energy substrates. For example, *Streptococcus bovis* and *Ruminobacter amylophilus* (starch digester) predominate when diets are rich in concentrate feed. *F. succinogenes* (fibre digester) and *M. ruminantium* dominate when low-quality roughages are fed. But most bacteria are generalists, such as *Prevotella ruminicola*, and *B. fibrisolvens* and others which work on a wide range of carbohydrates, or *S. ruminantium*, which utilizes sugars and as well as a variety of bacterial end products. Starch rich foods, and oilseed meals, are easily digested and when used in animal rations they stimulate the rapid growth of bacterial populations. The principal starch digesting bacteria are *S. bovis, R. amylophilus, Succinimonas amylolytica, P. ruminicola,* etc.

The fibre degrading microbes degrade feed to VFAs and supply the non-fibre digesting microbes substrates for their growth. The digestion of soluble carbohydrate mainly starch is limited by the protozoa which ingest starch granules make them unavailable to bacterial digestion. The form of forages influences the numbers and types of microbes in rumen. The grinding causes decrease in cellulolytic and propionate or lactate producing bacterial number increases which produce propionate and lactate in the rumen. The ciliates also feed upon the bacterial cells thus control the bacterial population in the rumen (antagonism). About one third of the methanogenic organisms are attached to protozoain therumen. Anaerobic fungi play a significant role in the degradation of plant cellulosic material by means of invading rhizoids and by producing a vast array of carbohydrate degrading enzymes. Methanogens comprise 0.3-3.3% of ruminal small subunit RNA (Janssen and Kirs, 2008) and are responsible for methane generation in the rumen. To develop the strategies to reduce methanogenesis, an understanding of methanogenic diversity in the rumen is essential.

The rumen microbes work together to get the benefits from each other (synergy) or work antagonistically. These conditions can be seen with the change in the diets or during feed change. There may be positive correlation or negative correlation between the various microbial communities depends on the composition of the diets fed to the ruminants. Joblin *et al.* (2002) established synergism between fibrolytic bacteria, fungi and *Methanobrevibacter smithii* in degradation of ryegrass and barley straw. Piao *et al.* (2014) reported that fibre digestion was temporarily halted until total hydrogen was utilized by methanogens. Since type of feed is the main factor for inducing microbial shifts in the rumen, various experiments have attempted to relate dietary shifts with microbial dynamics as well as with methane emissions. Pitta *et al.* (2014) demonstrated that switching from low energy (80:20 forage and concentrate) to a high energy diet (50:50 forage and concentrate) in transitioning dairy cows, showed reduced Firmicutes and increased Bacteroidetes populations. Kumar *et al.* (2015) conducted a study in dairy cows (Holstein) divided in two groups, one group fed with 80:20 roughage to concentrate and other group fed with 50% each. The genomic DNA was extracted from the collected rumen samples. Pyrosequencing study was done by using amplicons generated for each sample. Results showed that the anaerobic fungal concentration was highest in the group which fed high forage to concentrate ratio. But the methanogens diversity was not influenced by dietary composition. The methanogens, *Methanobrevibacter* and *Methanosphera* ogether constituted more than 98% of the archaeal abundance. Co-occurrence between different microbial domains showed that cows which fed with 75% forage, most of the genera found to potentiate each other. In the bacterial domain, members of Bacteroidetes and Firmicutes showed high co-occurrence with each other and with methanogens as well as with fungi. Among methanogens, *Methanobrevibacter* and *Methanosphaera* co occurred with each other as well as with fungi and bacteria. Within the fungal group, *Caecomyces, cyllomyces*, and other unclassified lineages of Neocallimastigaceae co occurred with each other as well as with bacteria and methanogens. At 50% forage level (reduced forage compared to previous group), the syntrophic interactions which appeared with high forage diet have reduced. The most distinct loss was observed within the fungal groups and between fungus and other domains. These results reveal that diet can have a huge impact on the associative patterns between different microbial communities in the ruminal microbiome. Change in the diet seem to changes these types of interactions. *Prevotella, Paludibacter*, and Bacteroidales (Bacteroidetes), Lachnospiraceae (Firmicutes) and *Methanobrevibacter* and *Methanosphaera* (archaea) showed strong associative patterns both within and between microbial domains indicating their inter-dependence.

Kittelmann *et al.* (2013) described the microbial co-occurrence patterns. They revealed that a general negative correlation between the methanognes of *M. ruminantium* clade and *M. gottschalkii* clade i.e. increase in one group population resulted in the decrease of the other. Both of these presumably compete within the rumen for hydrogen. Positive correlation reported between the occurrence of bacterial family Fibrobacteraceae and *M. ruminantium*. In contrast, *M. gottschalkii* clade occurred with bacterial family Ruminococcaceae. These two above mentioned bacterial species produce large amounts of H_2 and formate, which are substrates for these methanogens. There also exists the intra domain as well as inter domain interrelationships between the various microbial communities. All these were dependent on the type of diet given to the animals. A significant correlation was also observed between ciliate protozoa and anaerobic fungi.

Interaction between Rumen Microorganisms:

There are mainly 3 types of interaction between the rumen microbes. First, substrate can be digested by bacteria only after it has been partly degraded by other bacteria, protozoa or fungi. The starch-digesting bacteria cannot attack the starch in cereal grain endosperm cells until fibre degrading bacteria have digested the beta glucans polysaccharides of endosperm cell walls until fungi have digested the protein mesh in which that grain's starch are present (McAllister and Cheng, 1996). Secondly an organisms produced end product is utilized by another group of organisms as an energy source. The primary colonizing bacteria produce end products which attract secondary colonizers to the site of digestion to form biofilms. In symbiosis one species synthesizes a non-energy type nutrient which is required by other species. Carbon dioxide is required by the fibrolytic species which synthesizes the succinate. *Selenomonas spp*. use succinate as an energy source and in turn produce some of the CO_2, required by the fibrolytic bacteria. Similarly, lactate is a major end product of *Lactobacillus*, some species of bacteria use lactate as an energy source such as *M. elsdenii* which is a lactate utilizer. This sharing of substrate and end product is facilitated by the arrangement of bacteria in a synergistic association. Ciliate protozoa produce H from hydrogenosomes (an organelle inside cytoplasm), and fibrolytic bacteria also generates hydrogen which acts as a substrate source for the methanogens to produce methane. Methanogenic archaea adhere externally to protozoa and are found within protozoal cells too.

The interactions between bacteria are not always positively associated; there is severe competition (antagonism) for substrate in the rumen as the microbial population increases until reduced nutrient supply. Lactate-producing and fibre-digesting gram-positive bacteria produce bacteriocins to remove other bacteria which would compete for the available sources. Protozoa engulf bacteria and smaller protozoa and these serve as sources of nutrients. Thus, knowing the patterns of interactions such as synergism or antagonism between the rumen microbes may provide new evidences about metabolic networks between microbial groups present in the rumen and may elucidate their individual contributions to whole rumen functioning. Hence, in this complex microbial structure, it becomes clear that exploring the interactions between different microbial domains is the key to manipulating rumen environment/function through modifications in the microbial population and enhancing animal productivity as well as health, and also to reduce the environmental impact on animal production by changing or manipulating diets.

Conclusions:

The good gut health is very important for better production and health of livestock. The better knowledge in the evaluation and development of GIT conditions are linked with the nutritional interventions to optimize gastrointestinal functionality and the production of livestock and more attention are warranted of the researcher in this direction. The rumen microbes play important role in the utilization of feed by ruminants. Although some microbes have received attention of the researchers, but the roles of most microbes are still unknown. For improving livestock productions, the microbial structure and function needs to be explored. There are many gaps in knowledge about the interaction among different members of the rumen microbes and how these interactions affect the host metabolism.

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Chapter-3

Nutritional Strategies for Enhancing Reproductive Efficiency in Farm Animals

Narayan Dutta and Sonali Namdeo
Centre of Advanced Faculty Training in Animal Nutrition
ICAR- Indian Veterinary Research Institute, Izzatnagar
Email: dutta65@gmail.com

Dairy farmers have historically viewed the production of calves as the major product and milk as a byproduct. However, in order for their farming to be commercially successful, this mindset needs to alter. The reproductive efficiency in dairy animals is measured mostly in terms of early attainment of sexual maturity and number of calves during her entire life span. Under ideal management and feeding conditions the heifers should reach sexual maturity at an early age of 2.5- 3.0 years. The first calf should be produced early and subsequently at every 12 to 14 months interval. The productive and reproductive performances of the dairy animals are much lower than the desired optimal level. This may be due to poor quality of germplasm, poor nutrition and management and some other factors. Three main phases in dairy animal reproduction that influenced by nutrition are: breeding, pregnancy and lactation. i) breeding stage, nutrition influences the number of eggs released at mating and body condition after lactation; ii) nutrition affects the embryo survival in early and calf birth weight at late pregnancy; iii) nutrition modulates the milk yield and foetus growth rate. The primary nutrients that should be considered in providing for good reproduction are: energy, protein, minerals, vitamins and fiber. Fiber is listed as a nutrient since ruminants have a specific need for a minimum amount of fiber in order to maintain good rumen health and to prevent certain other metabolic disorders that may influence reproduction. There was no loss in reproductive performance in older cows as long as they were healthy and managed properly to keep them healthy (Ibtesham *et al*., 2018). During early lactation, the demand for nutrients to support maintenance and milk production is given the highest priority. Thus, reproduction takes a “back seat” until these demands for nutrients are met. The key to getting cows to milk to their genetic potential and to getting them bred back is to provide them with a well-balanced diet composed of quality forages, supplement and a mineral and vitamin mix. In rural areas most of animals are reared under grazing, cereal straws (wheat/paddy) supplemented with unbalanced supplements, sometime green fodder and occasionally balanced concentrate are feed.

Role of Nutrients on Reproduction:

Energy:

Energy is the most common nutrient limiting reproduction. For ensuring regular estrus cycle, ovarian cyclicity and optimum conception rates of the cows, nutrition in the postpartum period plays a critical role (Robinson *et al*., 2006). During early lactation, the peak in feed intake lags behind the peak in milk production. Milk production usually peaks approximately at six weeks of lactation, whereas feed intake peaks four weeks later at ten weeks after calving. During this ten-week period, the cow is in a negative energy balance. To meet their energy needs, cows rely on their body stores of fat. The occurrence of the first postpartum ovulation determines to a great extent how soon the cow conceives and is directly related to body condition at calving and body weight loss. Insufficient nutrient intake relative to metabolic needs is a significant factor leading to prolonged postpartum anestrus in cows (Jolly *et al.,* 1995). Cows gaining weight during early lactation have a higher conception rate and need less service per conception compared to those losing weight. Cows that lose an excessive amount of body condition or fat stores during early lactation have longer intervals to first ovulation and first estrus (heat period), lower first service conception rates and more days open. The recommended body condition score on the 1 to 5 scale (Mandour *et al.,*2015) at calving is 3.5 to 4.0 with acceptable body condition score loss after calving not to exceed 1.0 score. Therefore, animals calving with a body score of 3.5 and should not be less than a 2.5, five to seven weeks postpartum (Table 1).

Table1. Desirable Body Condition Scores by Stage of Lactation

Stage	**Body condition score (1-5 scale)**
Drying off	3.5-4.0
Calving	3.5-4.0
One month postpartum	2.5-3.0
Mid lactation	3.0
Late lactation	3.0-4.0
First lactation heifer at calving	3.5

Improvements in a cow's energy balance may be an important signal to the ovaries to start cycling. Cows may start cycling when they are still in negative energy balance but are starting to return to a positive value. When cows experience negative balance, the blood concentrations of non-esterified fatty acids (NEFA) increase, at the same time that insulin-like growth factor-I (IGF-I), glucose, and insulin is low. These shifts in blood metabolites and hormones might compromise ovarian function and fertility. It has also been reported that energy balance and dry matter intake (DMI) might affect plasma concentrations of progesterone (Ntallaris *et al.*, 2017), which may interfere with follicle development and maintenance of pregnancy. Preliminary results from research trials indicate that energy balance may also influence developing ova (eggs).

Heifers that are not fed adequate amounts of energy reach sexual maturity later. Dairy heifers reach sexual maturity when they are 30-40% of their adult weight. Heifers which are overfed will reach adequate weight at an early age but will lack sufficient bone growth, especially in the pelvic area, which increases calving difficulty. The level of energy intake in dairy animals is like sword with double edges, where the deficit or excess levels are always results in reduced reproductive efficiency. Excessive weight gain is more harmful to heifers before they reach puberty than after they are bred. Overfeeding heifers before puberty (before nine months of age) can cause heifers to store excessive fat tissue in the developing udder and decrease the amount of milk-producing tissue. Excessive energy intake during late lactation and also dry period cause “fat cow” problems which lower reproductive efficiency during the next lactation period.

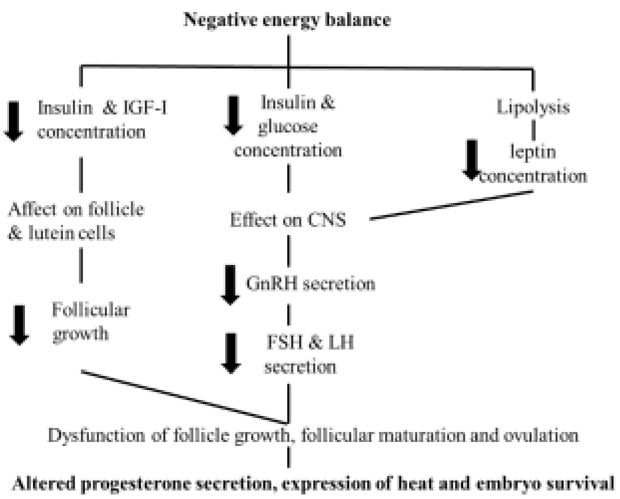

Fig. 1. Effects of negative energy balance on reproduction (Remppis*et al.*, 2011)

Protein:

Protein deficiencies in lactating cows may increase the incidence of silent heats (cow releases the egg but she is not seen in heat) and lower conception rates while at the same time decreasing feed intake and milk production. Inadequate protein and energy intake during early lactation can result in a low body condition score and an extended calving Interval (Laflamme *et al.,* 1992). Cows which are deficient in protein increase milk production within a couple of days when additional protein is added to the diet. Heifers that are raised on a protein-deficient diet lack the skeletal growth in relation to their size, especially in the pelvic area. These heifers are older when they start cycling, have more difficulty calving and may not milk as well once they enter the milking herd. Gaillard *et al.* (2016) provided a high energy density of **7**.81 $MJNE_L kg^{-1}$ of DM to Holstein cows and reported higher calving to first estrus, lower pregnancy rate and no effect on the total number of inseminations per pregnancy. Excesses of protein (CP 17-20% of diet) have been implicated in lowering conception rates with increases seen in the number of services per conception and days open. When an excess of degradable protein and/or a deficiency of energy is fed, ammonia not incorporated into microbial protein is absorbed into the blood stream. In turn, this excess ammonia and urea in the blood stream may decrease fertility at the same time energy is diverted away from milk production and/or reproduction. The excess degradable protein acts through some undefined mechanism to decrease uterine pH during the luteal phase, which may play a role in the observed reduction of fertility (Rodney*et al.*, 2018). The excess feeding of crude protein (16.3 -19.3 %) had lower progesterone concentration than the animals fed with low (12.7%) level of crude protein (Carder, 2016). This reduction in circulating levels of progesterone will be due to the energy expenditure in order to dispose the excessively degraded protein thereby resulting in negative energy balance even though the ration had recommended energy density. Studies have indicated that blood urea nitrogen (BUN) above 20 mg/ 100 ml may decrease the chances of pregnancy. The ideal proportion for combination of RDP and UDP (RDP: UDP) is 65: 35 which could be obtained by use of more than one cakes.

Macro Minerals:

Calcium (Ca): Low Ca level has been reported in anoestrus heifers. It is stated that GnRH stimulation of LH released from pituitary cells is calcium dependent and the LH is not released in absence of certain level of circulatory Ca or in the presence of Ca blocking agent. Reduced blood Ca may delay uterine involution and increases the incidence of dystocia, retained placenta and prolapsed uterus. Excess Ca may impair reproductive function by causing secondary deficiency of P, Mg, Zn, Cu and other trace elements. Cows diagnosed with clinical hypocalcemia were 3.2 times more likely to experience retained placenta than cows that did not have clinical hypocalcemia (Mordak *et al*., 2017). Whiteford and Sheldon (2005) also found that hypocalcemia was associated with occurrence of uterine disease in lactating dairy cows. Deficiency of Ca leads to prolongation of first estrus and ovulation, delayed uterine involution, increased incidence of dystocia, retention of placenta and prolapse of uterus (Kumar,2003). Both retained placenta and metritis can have devastating effects on reproductive efficiency in lactating dairy cows, with reduced conception rates and extended intervals to pregnancy (Goshen and Shpiegel, 2006).

Phosphorus (P): P is stated to be one of important element for normal sexual behavior (Satish Kumar, 2003). P deficiencies decrease fertility, feed intake and milk production. Most of the effect of P on reproduction is secondary to enzyme deficiency as P plays on important role in energy metabolism. However, even a marginal deficiency of P has a direct adverse effect on pituitary ovarian axis causing failure of onset of estrus. On contrary, the excess intake of phosphorus renders endometrium more susceptible to infection (Chaudhary and Singh, 2004).

Sodium and Potassium (Na & K): Both of these elements are indirectly related to reproduction in animals as the deficiency of former can affect the normal reproductive physiology by preventing the utilization of protein and energy where deficiency of later is well known to cause muscular weakness and thereby affect the musculature of female genital tract causing impairment in the normal reproductive process. The amount of Ca and P in mineral mixture should be around 22 and 11%, respectively and mineral mixture at the rate of 2% should be in the concentrate mixture is optimum performance and reproduction. Feeding of high levels of potassium (5% DM basis) may delay the onset of puberty, delay ovulation, impair corpus luteum (yellow body) development and increase the incidence of anestrus in heifers (Velladurai *et al*., 2016).

Trace Minerals:

Selenium (Se): Retained placentas are the most common reproductive problem associated with Se deficiency. But early embryonic deaths, increased metritis (an infection of the uterus), poor fertility, and the birth of dead or weak calves also are associated with low levels of Se.

Copper (Cu): A deficiency of Cu is associated with early embryonic death, reduced ovarian activity, delayed or reduced estrus activity, decreased conception rate, increased incidence of retained placenta, and increased difficulty in calving. The availability of copper is reduced by excesses intake of bivalent cations (Ca, S, Fe, Zn and Mo) in the diet or water. Copper and zinc are known to have a significant correlation with reproductive hormones (progesterone and estradiol) (Prasad *et al*., 1989) as they are specific activators of enzyme systems that assist in maintaining the activity of hormones in blood (Georgievskii, 1982).

Zinc (Zn): Zn is essential for proper sexual maturity (development of secondary sexual characteristics), reproductive capacity (development of gonadal cells) in males and all reproductive events (estrus, pregnancy and lactation), more specifically with onset of estrus in female. Zn deficiency reduces spermatogenesis (the production of sperm) in the bull, delays sexual maturity and can cause fetal abnormalities.

Iodine (I): Iodine has an indirect effect on reproduction through its action on the thyroid gland. Iodine deficiencies may indirectly cause early embryonic death, abortion, stillbirths, prolonged gestation, and an increase in the incidence of retained placenta.

Manganese (Mn): Mn deficiency is rare in ruminants. Cows deficient in manganese are likely to have poor development of the follicles, delayed ovulation, more silent heats, and lower conception rates. These cows also tend to abort and give birth to weak calves. Mn also has a significant role to play in maintaining the optimum fertility in the animals (Underwood, 1981)

Cobalt (Co): Cobalt deficiency is associated with an increased incidence of silent heat, nonfunctional ovaries, delayed onset of puberty, decreased conception rate, abortion and delayed uterine involution (Kumar, 2003).

Chromium (Cr): Chromium improves the energy balance which in early lactation leads to improved reproduction, as it influences the follicular maturation and lutinising hormone release (Chaudhary and Singh, 2004).

Vitamins:

Adding extra vitamins and minerals to the diet has often been suggested as a “golden bullet” solution to reduce infertility by various commercial interests, while requirements for optimal reproductive efficiency in modern dairy cattle deserve careful re-evaluation based on well-designed scientific research (Bisinotto*et al*., 2018).

Vitamin A: Vitamin A is the most commonly deficient vitamin in cattle. Large quantities of vitamin A can be stored in the liver and are mobilized as needed during periods when inadequate amounts are available in the diet. Nitrates and aflatoxin have been shown to destroy liver stores of vitamin A. Lactating and dry cows require 35,000 to 45,000 IU of vitamin A per day. Reproductive problems associated with a vitamin A deficiency include delayed sexual maturity, abortion, birth of dead or weak calves, retained placenta, metritis and shortened gestation periods. Supplementation with vitamin A should be considered when feeding poor quality forages or low amounts of green forage. β-carotene are a precursor of vitamin A. Early research showed that reproductive performance was improved when cows were supplemented with β-carotene and this serve as lipid soluble antioxidant. Olieveira *et al.* (2015) reported supplementation of β-carotene (600mg/d) or Vitamin A(120000IU/d) significantly reduced incidence of retained placenta.

Vitamin D: For normal calcium and phosphorus metabolism this vitamin is required. Its requirement in dairy cattle nutrition is 150 IU/lb of ration DM or 6000 to 12000 IU/cow. Deficiency may cause delayed onset of estrus and ovarian inactivity. During high Ca intake uterine involution was more rapid with vitamin D supplementation; however, with moderate Ca intake (100g), vitamin D appeared to delay uterine involution (Zinser and Welsh, 2004).

Vitamin E: The function of vitamin E on reproduction is not clearly defined. Selenium and vitamin E are closely related, but each is believed to function separately.

Strategies for Improving Reproductive Efficiency:

Effect of Concentrate Supplementation:

Supplementation through balanced concentrate mixture has been proven to be one of the easiest and economic ways to increase intake, digestion and performance of animals fed cereal crop residue/poor quality roughage-based diet. The effect of supplementary feeding on animal performance has been reviewed earlier by many authors. However, most of them did not include any reproduction parameter. Supplementary feeding also increases the plane of nutrition which favorably influences reproductive function. In case of supplementary feeding, a practical feeding situation is considered as standard. The response of supplementation is measured in terms of improvement in performance over the control. Supplementary concentrates may manifest their influence either through:

a) Increase in general nutritional status and improved body condition scores, which may shorten the onset of puberty and post-partum anestrus.

b) Strategic supplementation before mating (flushing) may improve ovulation/induce multiple ovulations and during pregnancy may improve lambing/kidding performance and improve post-partum reproductive efficiency of the dam.

Supplementation of paddy straw-based diet with as low as 1 kg of homemade concentrate mixture reduced the anestrus problem from 52 to 26% (Sonjaya *et al*., 2020). In a similar study conducted in other tropical developing country (Kanjonpruthipong and Buatong, 2002) indicate that 100% of the cows become cyclic in response to supplementation in comparison to only 54% of a control group. These studies clearly imply that reproductive disorders as observed in cattle fed on poor quality roughages can be ameliorated by supplementation.

Effect of Oil Seed Meals:

Oilseed meals are probably the most widely used supplement for straw-based ration. These supplements may be divided into 2 categories (highly degradable and low degradable) depending upon their degradation characteristics and they may act differently to influence reproductive performance. Providing soybean meal for 14 days before and 2 days after mating increased the fecundity by 0.5 lambs/ ewe. Excess of dietary RDP was reported to impair conception rate, when RDP was given in the form of soybean meal or urea (Rasby and Funston, 2016). Dietary fishmeal improved pregnancy rate from 32 to 41 % (Moallem,2018), however, other studies conducted on similar line showed no advantage of adding fishmeal over soybean meal. Similarly, liberal provision of RDP in the form of soybean meal was found to stimulate follicle recruitment, resulting in earlier ovulation, when compared with a less degradable source of protein, corn gluten meal. Dietary protein provides metabolizable protein by supplying both rumen degradable protein (RDP), which is used for microbial protein formation and rumen un-degradable protein (RUP), which is digested directly by the cow, which along with high-energy diets enhance microbial protein synthesis, thereby increasing the availability of this key source of metabolizable protein (Cadorniga and Satter, 1993).

Supplementation with Fat:

Inadequate dietary energy intake and poor body condition can negatively affect reproductive function. Supplemental lipids have been used to increase the energy density of the diet and avoid negative associative effects often experienced with cereal grains. Feeding of supplementary fat is being practiced by farmers, particularly for high yielding cows/buffaloes to maintain milk production and body condition. However, this may have some positive bearing on the reproductive performance of the cow. Fat supplemented cows had shorter interval between calving (McNamara *et al.,* 2003) and rapid uterine regression. An improvement of conception rate at first service to the tune of 13 to 17% was observed when the cows were fed with supplemental fat (McNamara *et al.,* 2003). Supplementary feeding of fat has been associated with shortening of anovulatory period post-partum (Useni *et al.,*2018). If the supplementation of fat fails to increase the DMI along with the increased milk production, then the cows are likely to be more prone to negative energy balance. In such situation, the response to supplementary fat on reproductive performance may not be observed (Kuhla *et al.,* 2016), the effective way is to fed fat in ruminally inert form usually as Ca-salt of long chain fatty acids (Yeasmin *et al.,* 2017), usually maximum response has been observed with those supplements like rice bran or rice bran oil containing higher proportion of oleic acid or linoleic acid (Prom and Lock, 2021).

Supplemental fat fed during the early postpartum period enhanced induced luteal function by reducing the incidence of short cycles. Mechanisms associated with the enhancement of mean serum progesterone concentrations in cyclic cattle, and the prolongation of corpora lutea destined to be short-lived, have not been definitively determined. However, the enhancement of luteal lifespan may be related to the ability of fat supplementation to modify growth and physiology of the preovulatory follicle before ovulation (Leroy *et al.,* 2018) This phenomenon could also be related to the effects of linoleic acid on uterine prostaglandin synthesis. Effects observed on serum progesterone during normal cycles may involve a decrease in metabolic half-life of progesterone in plasma or increased availability of cholesteryl esters in luteal cells (Soydan *et al.,* 2017). Based on dose-response studies of luteal cells to non-esterified cholesterol, it is possible that the supply of HDL-cholesterol within the ovary can be marginally limiting under conditions of extreme nutritional restriction (Wong, 2016).

Supplementation of PUFA may increase reproductive performance directly by improving uterine environment and embryo development, perhaps by increasing circulating concentrations of Progesterone hormone (Lopes *et al*., 2009). Omega-6 fatty acids are believed to have pro-inflammatory stimulating properties rendering them of extra value early post-partum, while omega-3 fatty acids can weaken this inflammatory potency, leading to a higher chance of survival of the embryo when supplemented during the peri conceptual period (Silvestre *et al*., 2011).

Effect of Green Fodder Supplementation:

Green fodder supplementation is one of the most efficient economic and farmers' friendly mean to increase intake, digestion and performance of ruminants fed poor quality roughages. Nevertheless, most of such experiments did not include any reproductive parameters. Supplementation of rice straw plus Napier based diet with a mixture of legumes at the rate of 20 % of total diet DM decreased the post-partum anestrus of Ongole cows from 115 to 67days. Supplying 20% of DCP through berseem increased the cyclicity from 25 to 50%. Similarly, supplementation of oat chaff-based ration with lapin increased both proportion of animals ovulated and multiple ovulations. Increasing the proportion of *Dolicbos lablab* from 30 to 50% increased the kid birth weight (1.9 to 2.4 kg) and kid growth rate (21.9 to 49.0 g/d) in goats fed maize stover based diet. Supplementation with as low as 2-3 kg green grass to cows fed on paddy straw and grazing reduced incidence of anestrus from 52 to 31%.

Supplementation of Area Specific Mineral Mixture (ASMM):

The efficacy of a supplemental mineral mixture on reproductive efficiency was assessed by Selvaraju *et al.* (2009) and they found that supplementation of the ASMM improved reproductive performance in crossbred dairy cattle. Out of the 110 crossbred dairy cattle examined, 73 were had reproductive problems such as postpartum anestrus and repeat breeding (28% each), followed by delayed puberty (21%), silent heat (10%), infectious endometritis of mild to moderate degree (10%) and cystic ovary (3%). Among the postpartum anestrus animals, 84.21 and 85.71% exhibited estrus and conceived, respectively, within 2 months of ASMM supplementation. Among the repeat breeders, which received the ASMM, 78.6% conceived within 2 inseminations. Onset of estrus occurred in 66.7% of the delayed pubertal animals, which received the ASMM supplementation. Among the silent heat animals, 66.7% conceived within 3 months of the ASMM supplementation. Similarly, effect of supplementation of deficient minerals (Ca, P, Cu, Zn and Mn) through area specific mineral mixture (ASMM) was studied in Chittoor district of Andhra Pradesh (Devasena *et al.,* 2010). They reported that among the animals under study, 60% of anestrous cows, 62% of repeat breeder's cows and 59% of anestrous heifers responded to supplementation, indicating the beneficial effect of mineral supplementation on their reproductive performance. Supplementation of wheat straw-based diets either with mineral supplement (@ 40-50 g/d) or both protein and area specific mineral supplement improved the reproductive performance of anestrus buffaloes (AICRP, 2020). There was significant reduction in number of days required for the animals to come to heat and services per conception in ASSM supplemented cows (Mohapatra *et al*., 2012).

Rumen Protected Nutrients:

Feeding of ruminally inert nutrients like protein, fat (Singh *et al.,* 2015), lysine and methionine (Trinacty *et al.,* 2009), choline (Garg*et al.,* 2012) and niacin (Shaver and Howard, 2001) either alone or in combination of two were reported to be favorably altered the reproductive performance during postpartum periods. Methionine, histidine and lysine are the amino acids with the greatest increase in concentrations in the uterine lumen during embryo elongation (>10-fold increase on average (Groebner *et al.,* 2011). Niacin supplementation at 6.0 g per day during pre-partum phase and the first 100 days of post-partum helpful in over-conditioned or ketosis-prone cows.

Phyto-additives:

Addition of some phytogenics to ruminant diets could enhance reproductive efficiency (Ahmed *et al*., 2020). *M. oleifera* leaf meal supplemented to the basal diet of lactating dairy cow at 60 g/d significantly increased the serum total antioxidant capacity, total protein, and IgG and reduced the levels of non-esterified fatty acids (Kekana *et al.,* 2019) thereby improving reproductive performance. Further, the inclusion of yucca in the diets of cattle (Cheeke, 2000) and dairy goats (Hassanien, 2014) enhanced the conception rates, shortened the estrus cycle, and increased the fertility and kidding rates in goats. *A. racemosus* have been shown to aid in uterine involution and enhance reproductive health by stimulating epithelial cell division and ovarian function (Sattar *et al*., 2007). Mallick and Prakash (2011) found that *T. cordifolia*, an immunomodulatory herb, enhanced immunity and early cyclicity in crossbred cows. Herbal feed additives in the diet of post-partum Tharparkar cows @ 150mg/kg BW noticeably improved the production and reproduction performance (Kaniga, 2024).

Conclusions:

Inadequate intake of nutrients and inadequate body reserves during early lactation are the major factors affecting reproductive performance of dairy cows. Improving energy balance by increasing energy intake through additional non-fiber carbohydrates or supplemental fat in the diet reduces days to first ovulation and improves conception postpartum. Strong evidence suggests that management of cows during the pre-partum period affects uterine health. Inadequate intake of nutrients pre-partum and altered feeding behavior increases the risk of metritis in dairy cows.

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Chapter-4

Precision Feeding: An Innovative Way for Affordable and Sustainable Animal Production

M.K. Gendley
Department of Animal Nutrition
College of Veterinary Science and A.H, Anjora, Durg
Dau Shri Vasudev Chandrakar Kamdhenu Vishwavidyalaya
Email: drgmanoj.ann@gmail.com

Introduction:

Feed represents the greatest single expenditure associated with livestock and poultry production. Nutritional research in livestock and poultry has therefore centered on issues related to identifying barriers to effective digestion and utilization of nutrients, and on approaches for improving feed utilization. Although livestock and birds are highly efficient in converting feed to food products, they still excrete significant amounts of unutilized nutrients.

One of the main objectives of raising livestock and poultry is to produce unadulterated wholesome food in the form of milk, meat and eggs to the consumers as a profitable enterprise with least contribution to climate change. Towards meeting this, they need to be fed with wholesome feed. Nutrition involves various chemical reactions and physiological processes that transform foods into body tissues and activities. It involves the ingestion, digestion and absorption of the various nutrients, their transport to all body cells, and the removal of unusable elements and waste products of metabolism. (Reddy., *et al* 2009).

Precision feeding provides the animal with the feed that precisely meet its nutritional requirements for optimum productive efficiency to produce better quality animal products (milk, meat and eggs) and to contribute cleaner environment and thereby ensure profitability. Cleaner environment means reducing the enteric emission of methane, excretion of nitrogen (ammonia), phosphorus and other compounds into the environment. It is aimed at supplying the nutrients to the animals matching their requirements to improve not only the animal physiology and health but also the enrichment of their products for the well-being of the consumer. (Reddy *et al.* 2009).

Precision feeding is formulating the ration to meet the nutritional requirements of livestock and poultry. This concept is about doing the right thing, in the right place, in the right way, at the right time. Precision feeding is based on the fact that livestock and poultry within a flock/farm differ from each other in terms of age, weight and production potential and therefore each have different nutrient requirements. Precision feeding involves the use of feeding techniques that allow the right amount of feed with the right composition to be provided at the right time to each livestock and bird in the farm. Precision feeding may be a powerful approach in reducing feeding costs and improving nutrient efficiency by reducing excesses of the most economically and environmentally detrimental nutrients without jeopardizing bird's performance.

The essential elements for precision feeding include: -

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

Advantages:

- Improved feed conversion
- Greatly reduced feed wastage
- Minimised growth stunts
- Better growth performance
- Better Reproduction Potential
- Increase Milk/Meat/Egg Production
- Decrease Metabolic/Production Diseases
- Reduce CO_2, Methane & N_2O Production (Green House Gases in Atmosphere)

Points to be Considered while Precision Feeding:

- Formulate rations based on amino acids instead of crude protein
- Select feeds with low nutrient variability
- Use "digestible amino acid digestibility" to formulate rations closer to amino acid requirements
- Include additives that reduce nitrogen excretion and enzymes that increase bird performance and diet utilization
- Avoid and control anti-nutritional factors that impede the bird's ability to absorb nutrients
- Use phase feeding

- Select ingredients with readily available phosphorus
- Use Phase Feeding with Least Cost Ration Formulation
- Feeding Total Mixed Ration and Complete Feed
- Use Protected Nutrients including Bypass Protein & Fat
- Use Ingredients with Readily Available Ca and P & Area Specific Mineral Mixture
- Strategic Supplementation of Roughage: Concentrate

Several factors influence the nutrient requirements in livestock and poultry includes livestock/bird type, breed and strain, age, sex, productive state of the livestock/bird, energy concentration, digestibility of nutrients, management, environmental temperature, anf/ toxins in feed, feed density, feed processing, feed form, deficiency or excesses of nutrients, nutrient imbalance& interactions and water quality.

Considering the requirement figures given by different agencies (ARC, NRC, ICAR, Dugessa etc.), for Energy, Protein/AA, Fat, Vitamins and Minerals, various feeding standard/ practices adopted in India and world. (Reddy.,2003) Detailed feeding strategy regarding precision feeding in cattle and poultry is mentioned below:

Precision/Phase Feeding in Dairy Cattle:

The growth/production cycle of an animal changes as the age advances. This phenomenon is more or less common with the different species of livestock. Thus, one of the most important feedings managemental is the precision feeding, which involves the manipulating the feed quantity/quality as per the nutrient requirement of the animal. The precision/phase feeding is a common practice used to implement feed programs. Ideally, to get maximum benefit from phase feeding, diets to be fed and feed budgets are established based on actual animal performance and profitability/performance goals. The correct diets and feed budgets must be established for each stage of production.

The feeding of livestock causes the major portion of rearing (About 65-75% in various species of livestock). Thus, any managemental step to reduce the cost of feeding will definitely improves the overall profitability of livestock farming. The feed provided should closely matches the animal's nutrient requirements and minimize the over- and under-feeding of nutrients. Thus, livestock gets the sufficient nutrients to meet to profitability/performance goals and can be prevented from the various parturition-disease complexes with maximum production. Use of phase feeding has been estimated to reduce N and P excretion by at least 5 to 10 percent. However, the disadvantages of moving from one feed to a phase feeding system includes greater complexity in ordering feed and the potential need to install additional feed bins on the farm (ICAR, 2013). However, with increased pressures on profitability, these disadvantages must be weighed against the benefits of improved animal performance and profitability.

A dairy cow produces milk for about 305 days, followed by a dry period of about 60days. During such cycle of 365 days, several aspects of the cow depend largely on the stage of lactation. The nutritional requirements vary with the stage of lactation.

For feeding practices, during this 365-day period, 5 distinct phases will be categorized:

Phase 1: Early lactation: 0 to 70 Days in milk (Peak milk production)

Phase 2: Mid lactation: 70 to 200 Days in Milk (Peak DM feed intake)

Phase 3: Late lactation: 200 to 305 Days in Milk (Restoration phase)

Phase 4: Dry period: 60 to 14 days before the next lactation

Phase 5: Transition or close-up and Fresh period: 14 days before and after calving

Transition or Close-Up Period Nutrition:

Transition period is a time frame from 3 weeks before calving to 3 weeks after calving. Feeding during transition period determines the cow's productivity during the preceding lactation period. Providing the right nutrition during this period greatly improve the calving ease, cow and calf welfare, milk production and reproductive performance. Smooth transition from pregnancy to lactation is essential for the better productive and reproductive performance of the dairy cattle. Failure in transition leads to lowered milk production, immunosuppression, poor reproductive performance. Decline in Dry Matter Intake (DMI) during transition period results in negative energy balance (NEB) which leads to increase the level of NEFA and ketone bodies in blood (Krishnamoorthy. 2013). This predisposes the animal to metabolic disorder like milk fever, ketosis and increase the incidence of mastitis, which affects the productivity of cow. Precision feeding significantly reduces the amount of DMI, and lowers the release of N and P into the environment. It also reduces ration costs and costs associated with manure management. (Praveen *et al* 2018)

In view of the dynamic nature of physiological changes during the transition period, goals of nutritional and environmental management during this period can be summed up as:

- Maintain (or enhance) immune function.
- Minimize the extent of body fat mobilization around calving.

- Maintain blood calcium at and after calving.
- Maximize appetite of the cow at and after calving. (Drackley., 1999, Praveen *et al.,*2018)

Potential Consequences of an Inadequate Transitional Program includes:

- Metabolic Disorders-Milk fever, Fatty liver and Ketosis
- Reproductive Disorders-Retention of Placenta (ROP)and Metritis
- Digestive Disorders-Subclinical Rumen Acidosis (SARA) and Displaced Abomasum (DA)
- Rapid & Excessive Loss of Body Condition in Early Lactation
- Low peak Milk yields
- Poor Fertility
- High Veterinary Costs and
- High Involuntary Culling Rates.

Nutrient Requirement and Feeding Strategies during Transition Period:

A. DMI and Fiber level:

Total Dry matter intake in the ration should be 1.75-2.0% of Body Weight with more than 50-55% of fibre DMI which is 1.4% of Body weight having Atleast1.5 inches Long With NDF above 35-40% of Total Ration DM.Rumen adaptation Despite recent changes in management to provide more energy dense rations in the transition period, dry cow rations will continue to have a lower energy density than lactating cow rations and a lower content of fermentable carbohydrate, even in pasture-dominant feeding systems.

There is evidence that part of the adaptive process in the rumen involves the elongation of ruminal papillae and an increase in absorptive area of the papillae. Further, there is a need to allow rumen microbial populations to form a stable ecosystem based on greater activity of amylolytic, that is starch-utilising bacteria. These bacteria, which include *Streptococcus bovis* and *Lactobacillus* spp., produce lactic acid, a strong acid which can markedly lower rumen pH. Lactic acid utilising bacteria, including *Megaspheraelsdenii*, *Selenomonasruminatum* and *Vionella species*, produce propionate from lactate, thereby moderating the effects of starch feeding on rumen pH. A failure to successfully adapt rumen physiology to diets higher in starch places the cow at risk of sub-acute ruminal acidosis (SARA) and lactic acidosis. It has been suggested that the lower absorptive area of ruminal epithelium may reduce the rate of absorption of volatile fatty acids and lactic acid from the rumen. (Lean *et al.,* 2010).

B. Managing Protein Balance:

The potential value of this strategy of supplementing ruminally protected methionine (RP-Met) has been exploited where supplementing RP-Met to a 14.7% CP diet resulted in milk protein secretion equal to that of 16% CP diet, but at 31 versus 27% conversion of dietary N to milk N. Rumen-protected amino acids improve the digestion and absorption and thus could reduce the N content in the diet and faeces simultaneously. (Reddy *et al*.,2009). Experiment conducted by Effect of Rumen Bypass Amino acids on Milk Yield & Milk Protein yield during Prepartum and Postpartum Phase found that there is increase in milk yield as well as milk protein yield.

C. Use of Fat in Transition Diet:

While the feeding of fat supplements during the pre-partum and immediate post-partum period has not traditionally been recommended due to the potential to reduce dry matter intakes, particularly in heifers (Hayirli *et al*., 2002), there have been several studies where potentially beneficial effects have been observed. There have also been other studies that showed no beneficial effects. The potential for any reduction in NEFA or liver triglyceride to be secondary to reduced dry matter intake during the pre-partum period means any benefits must be carefully weighed up against the detriment effect of reduced feed intake. It is possible that the form of fats may be important in modifying responses. Protected fats, that is fats that are not as available to ruminal modification, including calcium soaps and prills, may provide energy in forms that have less effect on feed intake and can provide specific fatty acids. (Lean *et al*.,2010).

Sharma *et al*., 2009 found that by supplementing fat found that there is decrease Non esterified Fat (NEFA) which reduces ketosis in dairy animals. Feeding fat 6-7% of DM during entire period abolished accumulation of Triglycerides and Decreases DMI. Decreased incidence of disease in early lactation can result in increased milk production throughout the lactation. It is stated that supplementing ration of lactating animals with bypass fat enhances energy intake in early lactation which reduces deleterious effect of acute negative energy balance on lactation (Tyagi *et al*., 2010).

D. Role of Cation-Anion Supplement in Diet:

Anionic (chloride and sulphate) salts are often used in pre-fresh diets to counteract the effects that high dietary potassium (K) and sodium (Na) concentrations have on increasing hypocalcaemia. Reducing K and Na concentrations and the use of anionic salts lowers the cation-anion difference (DCAD) of pre-fresh diets, which helps control milk fever, retention of Placenta, Abomasal Displacement, and ketosis. Because the addition of large amounts of anionic salts to the diet may depress DMI, we recommend that restriction of dietary potassium and sodium concentrations be considered first. Feeding forage with a high K content is often the culprit causing high DCAD diets. Alfalfa normally has a high K content (2%- 4% of DM) and, depending on soil fertility, grass and small grain forages may also test this high. Corn silage normally has a low K content (about 1% of DM), and can be used to dilute out high-K forages in the diet. Other strategies for lowering dietary K content include the purchase of low-K hay and targeted soil fertility for the production of low-K forage. Commonly used anionic salts include ammonium chloride, ammonium sulfate, magnesium sulfate (Epsom salts), calcium sulfate (gypsum), and calcium chloride. Because chloride salts are more effective acidifiers of blood and urine than sulfate salts, the use of calcium chloride, ammonium chloride, and hydrochloric acid have become more common. The use of magnesium sulfate in anionic salt mixtures is still common because it is a good source of magnesium and is more palatable than most other salts. The efficacy of anionic salt mixtures can be evaluated by measuring urine pH, which should average between 6.0 and 6.5 in Holstein cows for control of milk fever. The recommended calcium concentration in pre-fresh diets containing anionic salts is 1.0% - 1.2% (DM basis). Pre-fresh diets should contain .4% magnesium (DM basis). Anionic salt products should not be fed to post-fresh cows. (Shaver *et al.,* 2014).

E. Role of Feed Supplement in Diet:

Calcium Propionate: Use @ 0.11kg/Cow/dayin transition cow diets as a glucose precursor. Sodium propionate should not be used in pre-fresh diets because it will elevate DCAD. There is limited research showing reduced serum NEFA and reduced urine ketones in response to adding calcium propionate at the rate of 4 ounces/cow/day to transition diets. Calcium propionate also enhances bunk stability and because of this may improve DMI in situations where heating of the TMR in the feed bunk is a problem. **(**Shaver *et al.,* 2014**)**

Biotin: Shaver *et al.,* 2014 found that supplementing Biotin at 20 mg/cow/day has been shown to improve hoof health in several trials. Milk yield increases of 1-1.5 kg/cow/day have been observed, but not in all trials. The cost of supplementation is 5 - 7 cents/cow/day. Several months of supplementation will be required to improve hoof health.

Niacin: Feeding 6 to 12 grams of niacin per cow per day helps prevent ketosis and promotes dry matter intake to close-up dry cows and over-conditioned, ketosis-prone cows. Feed niacin until maximum DMI has been achieved usually within 10 weeks after calving. Do not feed niacin to thin cows as summed to be cows below a 2.0 body condition score (BCS) (Schroeder., 2001)

Choline: 28% of absorbed Methionine used for Choline synthesis. Feeding 12gm of Rumen Protected Choline (RPC)/day in Combination with the low Rumen Undegradable Protein (RUP) in Prepartum diet increase Milk Production during the first 56 day of Lactation (prepartum RUP × RPC, $P < 0.05$) (Hartwell *et al*.,2000)

F. Benefits of Buffer, Ionophores in the Diet:

Free-choice Bicarbonate may benefit early lactation or high producing cows and cows under heat stress, but may need to be mixed with salt to limit its intake and should not replace what is provided in the TMR. Sodium or potassium buffers should not be fed to dry cows, because of effects of elevated DCAD on hypocalcaemia. Feeding Monensin @ 200 Mg/Day during Prepartum reduce BHBA Production, so prevent Ketosis.

- Maintain pH of Rumen
- Maintain the Microbial Flora of rumen
- Decreases the Incidence of Ruminal Acidosis followed by Lameness

Reasons for Immunosuppression during this Phase includes:

- Oxidative Stress
- NEFA
- Ketones
- Negative Energy Balance
- Calcium Status

G. Role of Antioxidant and Trace Minerals on Immunity during Transition Phase:

Vitamin E: It is an important lipid soluble antioxidant that protects against free radical-initiated lipid Vitamin E is an important lipid soluble antioxidant that protects against free radical-initiated lipid peroxidation (Halliwell and Gutteridge, 1999). Fresh green forage is an excellent source of vitamin E. However, concentrates and stored forages (hays, haylages, and silages) are generally low in vitamin E (NRC, 2001).

Selenium: The Se requirement of dairy cattle is approximately 0.3 mg/kg diet (NRC, 2001). Although the requirement for Se is relatively low, feedstuffs produced in many areas of the world contain considerably less than 0.3 mg/kg, necessitating the need for supplementation. Selenium functions in the antioxidant system as an essential component of a family of glutathione peroxidase enzymes. These enzymes destroy hydrogen peroxide and also lipid hydroperoxides. Thiore doxin reductase is another selenoenzyme that may function to prevent oxidative stress (Mustacich and Powis, 2000).

Copper: It is involved in the antioxidant system via its involvement in the enzymes Cu–Zn superoxide dismutase (SOD) and ceruloplasmin. Copper–Zn SOD is responsible for dismutation of superoxide radicals to hydrogen peroxide in the cytosol (Halliwell and Gutteridge, 1999). Cerulo plasmin is a Cu transport protein that also exhibits oxidase activity. It oxidizes ferric iron (Fe+3) to ferrous iron (Fe+2) without the production of free Fe+3 that can cause oxidation and peroxidation to tissues (Halliwell and Gutteridge, 1999). Ceruloplasmin is an acute phase protein that increases during disease and may be important in scavenging superoxide radicals (Broadley and Hoover, 1989). Copper deficiency in cattle is generally due to the presence of dietary antagonists, such as sulphur, molybdenum and iron (Fe) that reduce Cu bioavailability (Spears, 2003). Dietary requirements for Cu are greatly increased by high concentrations of molybdenum and sulphur.

Chromium: The primary role of Cr appears to relate to its ability to enhance the action of insulin. Requirements for Cr in dairy cattle have not been defined (NRC, 2001). However, studies have indicated that Cr supplementation may affect health and immune response in stressed calves (Spears, 2000). Several other reports also indicate that Cr supple mentation can significantly affect feed intake and milk pro duction in early lactation dairy cows (Hayirli *et al.,* 2001). In these studies, Cr was supplemented from 21 to 28 days pre-par tum until 28 to 35 days post-partum.

Zinc: It is an essential component of numerous enzymes including enzymes involved in the synthesis of DNA and RNA. In the antioxidant system Zn is a component of Cu–Zn SOD. Zinc also induces synthesis of metallo thionein, a metal binding protein that may scavenge hydroxide radicals (Prasad *et al.,* 2004). In addition to an antioxidant role, Zn may affect immunity via its important role in cell replication and proliferation (Weiss and Spears, 2006).

Beta-Carotene**:** Supplementation may Enhance Immunity and reduce the Incidence of retention of placenta (ROP) and Metritis.

Precision Feeding Practices in Poultry:

Under precision feeding in poultry various practices are adopted now a days-

1. **Ideal Protein Concept:**

The ideal protein concept uses Lysine as the reference amino acid, and the requirements for other essential amino acids are set as percentages (or ratios) of the lysine requirement. (Elangovan.,2013)

2. **Digestible Amino Acids:**

Feeds are to be formulated on the basis digestible amino acids rather than on total amino acids. For formulation on digestible amino acid basis, there will be accuracy in AA requirement. (Dugessa., 2016)

3. **Estimating Nutrient Composition and Feed Ingredient Quality:**

- Due to fluctuation of Feed Ingredient cost- Poultry producers are continually looking for opportunities
- Advances in Nutrient Analysis and Feed Evaluation Technologies.
- Bird Digests and Utilizes for productive functions.

4. **Feed Management Technologies:**

By targeting animal nutritional needs, PF can reduce nutrients excreted in faeces or urine while maintaining or even improving animal production & the economic viability of an animal operation. Reducing the nutrients in manure lowers airborne emissions. PF managemental techniques include: separating animals according to nutritional needs and production potential, limiting excess nutrients, and improving the efficiency of nutrient absorption. (Vasan,.2017)

5. **Limiting Excess Nutrients:**

Excess nutrients not absorbed in the digestive tract are voided in the excreta. Dietary protein provides amino acids, nitrogen, sulphur, and other elements needed for reproduction, growth, and egg production. Birds use less than half of the nitrogen that they consume, with the remaining excreted in the faeces. Limiting crude protein levels in the diet to only that used by the bird limits nitrogen excreted in uric acid, which contributes to emissions. While reducing crude protein content will reduce nitrogen excretion and ammonia emissions, reductions in crude protein can severely impact bird's performance. To effectively reduce crude protein concentrations of diets for swine and poultry, additional supplementation of synthetic amino acids is needed. Birds require a specific profile (ratios) of available amino acids; thus, lowering crude protein levels requires supplementation with select amino acids that otherwise would be insufficient. Specific synthetic amino acids can be added to meet the nutritional needs of a bird according to genetic lines, age, sex, and other factors. (Vasan,.2012)

6. Phase and Split-Sex Feeding:

Two types of animal separation practices are used for precision feeding: phase feeding and split-sex feeding.

A. Phase Feeding: For phase feeding, animals/birds are separated by age or production state (e.g., birds at different physiological stages), and diets (e.g., nutrients) are matched to the different nutritional needs of each phase. (BIS.,2007)

B. Split-sex feeding: Animals/bird are separated by sex, and diets (e.g., nutrients) are adjusted accordingly. Phase feeding is commonly used currently, but split-sex feeding is yet to be practiced due to its practical difficulties. In case of broilers this type of feeding strategies is feasible. E.g. ME, Standard Digestible AA & other Nutrient Requirement of Male & Female Broiler and Broiler Breeder and Layer Breeder Nutrient Requirement in Poultry.

Conclusion:

Precision feeding can contribute to improve the sustainability of farms through direct (e.g. reducing N excretion) and indirect (e.g. allowing higher milk yield) actions. Precision feeding prevents many disorders and increases production/reproduction performances. Excellent nutrition and feeding management during the transition period helps to maximize the dry matter intake after calving and ultimately leads to higher milk production. Technology can be of great help by providing more precise and short-term information to be used as input in diet evaluation models. Precision feeding means higher accuracy in the evaluation of the actual animal requirements and also higher accuracy in the evaluation of the effective diet nutrient allowances. Precision feeding does not necessarily aim to obtain maximum production but should aim at the right balance between production, animal welfare, and economic return, environmental and social impact.

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Chapter-5

Nutrition and Metabolomics in Animal Health Management

A. Sahoo and Dr. Ganesh N. Aderao
ICAR- National Institute of Animal Nutrition and Physiology
Bengaluru
Email: sahooarta1@gmail.com

Nutrition and health are of paramount importance for the profitability of livestock business. For instance, nutrition comprises of 70% of total production cost and any perturbations in health may lead to losses exceeding 50%. Consequently, nutritional modulation to maintain better health and production has always been the topic of interest to livestock farmers, researchers, and animal nutritionists. Lately, due to awareness and increased purchasing power, the preference of consumers has shifted towards consumption of quality animal foods instead of mere animal origin foods. The increased demand for quality animal produce has advanced the science on quality assessment, and product quality and shelf-life improvement. The advancements were partly made possible due to the high throughput techniques such as genomics, transcriptomics, proteomics, and metabolomics. Metabolomics is the downstream of all these throughput techniques, considered as the most comprehensive illustration of an individuals' phenotype. Metabolomics gives a snapshot of low molecular weight metabolites present in given body- or bio- fluids. It portrays the true picture of intermediary metabolism, chemical reactions undergoing, and the metabolites present in the body. Being dynamic in nature, metabolome of individual depends upon the genetics, external environment, health status, and nutritional interventions. Accordingly, nutrition and metabolomics has emerged as a crucial field in animal health management. Here, we have tried to make aware about the latest advancements in understanding how nutrition influences metabolic processes, and how metabolomics can be employed to assess and maintain animal health, productivity, and welfare.

Animal Nutrition and Health:

Animal nutrition encompasses all physical, biochemical, and physiological reactions by which broken down to simpler molecules, absorbed through gastrointestinal tract, metabolized to useful substances, and the waste products are removed from the body. Animal nutrition is primarily based on supply of essential macro-and micro- nutrients for maintaining health, improving production and reproduction performance, improving feed efficiency, and lowering feed cost and environmental pollution. The variety of feed additives such as probiotics, prebiotics, postbiotics, symbiotic, Para probiotics, stim biotics, organic acids, and phytogenic compounds has gained prominence in recent years due to their sustainable impact on livestock production. Most feed additives used in ruminant diet aid in improving health and production performance through modulation of rumen fermentation. For instance, plant secondary metabolites namely, essential oils, polyphenols, and organic acid salts are reported to alter rumen fermentation and thereby improve production performance, feed efficiency, and health status of livestock (Pal *et al*., 2015; Aderao *et al*., 2019; Aderao *et al*., 2020; Bhatt *et al.,* 2021). Lately, the focus of feed additives and nutrient modulation has expanded to production of quality animal products such as antioxidant, essential fatty acid, conjugated linoleic acid, mineral and vitamin enriched milk products namely milk, meat and eggs. The enrichment of animal products involves various biochemical reactions and several unexplored metabolites that have positive impact on health of both livestock and humans. Accordingly, the metabolites and their precursors in animal body need to be assessed which can be further used in production of healthy animal origin products; wherein, metabolomics can be of great help. Besides, the metabolome of an individual will also indicate any perturbations in normal metabolic processes and their impact on health and nutritional status.

Macro-Nutrients and Health:

Macro-nutrients are the nutrients supplied to and required by animals in higher quantities such as proteins, fats, and carbohydrates. The proteins are made up of amino acids, some of which are essential and need to be supplied through the diet for high yielding dairy cattle and all types of poultry. The amino acids are imperative for synthesis of chemokines, immunoglobulins, and production and maturation of immune cells. Further, amino acids are involved in synthesis of mucus and antimicrobial peptides in body secretions that aid in prevention of pathogen entry and multiplication thereby lowering the incidence of infectious disease. For instance, leucine, isoleucine, and valine are crucial for growth and multiplication of immune and phagocytic cells, and imperative for synthesis of antibodies against variety of infectious disease. Supplementation of rumen protected methionine is observed to enhance the serum concentration of glutathione, taurine, and methionine that have role in improving antioxidant status besides its positive impact on milk production, milk fat and milk protein. Methionine is crucial for single carbon metabolism and consequently, immune cells growth and maturation. Further, methionine supplementation is observed to lower the incidence of mastitis and reproductive disorders in high yielding dairy cows. The threonine is also involved in single carbon metabolism and subsequently plays a crucial role in immune response. There is paucity of information on studies of threonine supplementation in ruminants; however, studies in pigs and poultry have widely indicated its significance in lymphocyte transformation, gut integrity, mucin synthesis, immunoglobulin A production, and chemokines production.

Carbohydrates are predominantly used for energy supply to all the cells of body, including immune and phagocytic cells. Besides, carbohydrates are imperative for tissue healing, synthesis of hormones and enzymes responsible for maintaining immune and antioxidant status. Herein, energy deficit is negatively correlated with the hormone synthesis involved in reproduction such as progesterone and estrogen. Besides, glucose is imperative for maintaining antioxidant status due to its role in synthesis of NADH and NADPH required for regeneration of vitamins responsible for antioxidant effect i.e. vitamin E and vitamin A. In ruminants' carbohydrates are of specific importance as they provide bulk for rumen fill and is a source of nutrients (volatile fatty acids and microbial proteins). The level of fibrous carbohydrates is of paramount importance for rumen health of dairy cattle, and gut motility and integrity in simple stomach animals. Unlike carbohydrates, fats are components of cells and are precursor for various molecules involved in maintaining immune and antioxidant status thereby help in lowering the incidence of infectious and non-infectious disease in ruminants and simple stomach animals. The composition of fats is crucial as excess of dietary unsaturated fatty acid may lead to hard fat and deficiency of essential fatty acids. Contrarily, in ruminants excess of unsaturated fats lower the rumen fermentation and negatively affect the rumen microbial population.

Micro-Nutrients and Health:

During the last two decades, the scope of animal nutrition research has expanded to maintaining animal health vis a vis production. Earlier the focus of nutrition in health management was limited to the prevention and control of peripartum diseases/metabolic disorders and deficiency diseases. For instance, the macro- and micro- nutrient management of livestock is thoroughly studied by various researchers at different locations around the globe to manage the negative energy balance and resulting ketosis in high lactating cattle and pregnancy toxemia in multiple fetus bearing sheep. Further, management of micronutrients e.g. calcium, phosphorus, sodium, potassium, chloride, and sulphur are widely studied to prevent the incidence of milk fever and consequent losses. Nowadays, nutritional modulation is also carried out to prevent and treat infectious and non-infectious diseases in livestock and poultry. The dietary interventions affect the health in various ways:

- Supplying essential nutrients to the immune system for better immune response
- Help in repair and growth
- Inhibits the growth of pathogen
- Increases phagocytic activity
- Aid in production of interferons and antimicrobial peptides
- Expulsion of endoparasites
- Improving the function of physical barriers of livestock body.

Most often, disease conditions are characterized by increased oxidative stress due to their role in defense mechanisms of immune system; wherein, the proliferation and activity of phagocytic cells is remarkably increased. The phagocytic cells remove the infectious organisms from the body through oxidative burst. Accordingly, dietary interventions focusing on lowering oxidative stress may improve health status and thereby negating the deleterious effects of diseases on production performance. For instance, vitamins and trace-minerals are frequently used for ameliorating the oxidative stress because of their role in neutralization/inactivation of oxidants and in synthesis of antioxidant enzymes, respectively. A study by De *et al*. (2017) observed improved antioxidant response in selenium yeast fed sheep exposed to heat stress compared to non-supplemented group. Similarly, a study by Aderao *et al*. (2023) reported enhanced immune and health status of rats fed higher dietary selenium levels under heat stress condition. Dairy animals exhibit marked immunosuppression during the transition period (3 weeks prior and 3 weeks after pregnancy) wherein they are susceptible to numerous infectious diseases (Mallard *et al*., 1998). The immunosuppression during transition period is primarily contributed by significant increase in level of oxidants such as reactive oxygen species, reactive nitrogen species, and other free radicals. Accordingly, Chen *et al.* (2023) reported that supplementation of Se (0.3ppm) and Vitamin E (1500 IU) enhances immune status, reproductive performance, and milk yield with no effect on negative energy balance. Further, they found improvement in immune and antioxidant status, and milk yield with supplementation of copper (Cu; 5 pppm), zinc (Zn; 12.5 ppm) and manganese (Mn; 7 ppm). Dur to interaction among minerals at gastrointestinal tract, the inorganic salts of minerals are reported to have lower bioavailability and increased excretion into the environment. To address this, organic minerals and nano-minerals concept has been explored in livestock feeding. Organic minerals are synthesized by combing the mineral salts with organic molecules viz. amino acids, peptides, simple carbohydrates etc. which prevents the interaction and are absorbed as per the mechanism of attached organic molecules resulting in improved bioavailability. Pomport *et al.* (2011) conducted a study on total replacement inorganic Cu, Zn, and Se with respective organic/chelated sources to assess its effect on health and performance of high producing dairy cows. They observed reduction in rate of mastitis, number of inseminations for pregnancy, somatic cell count, lameness, and enhancement in milk production, lactose content, and pregnancy rate with organic mineral supplementation. On the other hand, nano-minerals are minerals whose size is reduced to less than 100 nm, which results in altered phyico-chemical properties resulting in no interaction with other minerals and therefore improved bioavailability. Besides, nano-minerals are known to improve health and immune status of livestock. On this line, Pandey *et al*. (2022) observed improvements in antioxidant status and reduction in incidence of diarrhea in calves fed on nano-Zn and nano-Cu.

Among fat soluble vitamins, vitamin E, vitamin A, and vitamin D are reported to have role in immune response, antioxidant status, and health. Vitamin E and vitamin A (or beta carotene) are imperative for maturation of phagocytic cells, enhance chemotaxis and neutrophil function. Besides, vitamin E plays crucial role in synthesis and release of interleukins and interferons from respective cells. Moreover, vitamin E and beta carotene supplementation is found to lower the peripartum disease, mastitis, and infertility issues in high yielding dairy cows (Spears and Weiss, 2008). More recently, vitamin D is studied for their non-skeletal role and is observed to play crucial role in lowering the respiratory tract infections (paratuberculosis) and peripartum diseases that was attributed to the widespread presence of vitamin D receptors on variety of immune cells (Nelson *et al.,* 2012; Hodnik *et al*., 2020) and their role in cell maturation. The water-soluble vitamins are involved in supplying energy to immune cells through the variety of coenzymes of which they are part of. Post-activation, immune cells demand high energy and nutrients including water soluble vitamins; therefore, supplementation of water-soluble vitamins namely B complex can be of great help. Vitamin C have role in connective tissue proliferation and antioxidant mechanisms, which when supplemented to the immune compromised dairy cattle is reported to ameliorate the deleterious effects of disease conditions.

Metabolomics: An Overview:

Metabolomics involves the systematic analysis of numerous small molecule (<1000 Dalton) metabolites in given biological samples that are intermediates or end-products of metabolic processes. The set of molecules/metabolites is known as metabolome, comprised of amino acids, lipids, carbohydrates, nucleotides, and other organic compounds. The metabolome is highly dynamic and is affected by both internal and external factors, making it a reliable indicator of animal's physiological state. Consequently, the metabolomics technique is crucial for offering valuable and novel insights into the complex interactions between diet, environment, and physiology of animals. Besides, metabolomics evaluates alteration in metabolome by disease conditions that may be useful for differential disease diagnosis and timely treatment and aid in preventing further losses. Primarily, two analytical platforms dominate metabolomics research i.e. Nuclear Magnetic Resonance (NMR) spectroscopy and Mass Spectrometry (MS). These two high throughput techniques are capable of identification and quantification of variety of metabolites simultaneously. Any one or both techniques can be employed for metabolomics study; however, the technique to use is based on the sensitivity and specificity required and identification of novel compounds. These two techniques are briefed below.

a) NMR Spectroscopy:

The NMR is based on *Zeeman* effect i.e. strange behavior of nuclei when subjected to strong magnetic field. NMR determines physical and chemical properties of atoms or molecules by understanding their magnetic properties. Further, it gives information about the chemical shift that helps in understanding the composition of atomic groups within molecules. Besides, it can provide information of adjacent items and molecular dynamics along with molecular structure and quantitative information about the novel compounds. This technique has the inherent advantage of high reproducibility and requires minimal sample preparation and is non-invasive in nature. However, it has its own limitation of lower sensitivity compared to mass spectrometry. The commonly used nuclei for NMR spectroscopy are ^{1}H and ^{13}C. Metabolomics studies primarily exploit the ^{1}H (proton) nuclei for evaluation of variety of metabolites present in biofluids. The NMR spectroscopy provides additional information, particularly structural explanation of the novel metabolites.

b) Mass Spectrometry (MS):

Mass spectrometry is a technique that measures the mass to charge ratio of ions resulting from mass spectrum. Herein, the sample is ionized by employing a beam of electrons that turns the molecules into positively charges ion. These ions are separated based on mass to charge ratio giving out unique deflection, detected by electron multiplier. The high-resolution MS is often coupled with liquid chromatography (LC-MS; for polar and non-polar compounds) or gas chromatography (GC-MS; for volatile compounds or those that can be derivatized) which allows for the simultaneous detection and quantification of several metabolites. Contrary to NMR, MS-based methods yield high sensitivity and can detect a broader range of metabolites.

Metabonomics in Animal Nutrition:

As discussed, metabolomics gives a snapshot of all the metabolites present in body fluid at a given time. Recently, metabolomics, a new term which is apt for studying the metabolomic response of diet, drug, and specific disease condition. The metabonomics is a subset of metabolomics and is defined as quantitative measurement of multiparametric metabolic response of animals to pathophysiological stimuli, genetic modifications, and environmental and nutritional stressors. Metabolomics has significantly enhanced our understanding of animal nutrition in several key areas:

Feed Efficiency and Nutrient Utilization:

Better feed efficiency of livestock and poultry are the prime desired characteristics for farmers, nutritionists, and breeders. Consequently, feed efficiency is frequently assessed by various ways that include feeding trials, and measurement of production performances and residual feed intake. The knowledge about the feed efficiency of dairy animals at the time of purchase (for both production and reproduction purpose) can be an effective strategy for improving the profitability of livestock business. Herein, metabolomics is of high significance to explore and identify biomarkers responsible for and/or correlated with higher feed efficiency. Besides, breeders can make use of metabonomics and exploit the germplasm for superior feed efficiency. However, mere correlation of a metabolite with feed efficiency will not solve the purpose of improving feed efficiency in next generation; wherein, heritability of the particular trait is of importance. For instance, Su *et al*. (2022) found that nearly 124 metabolites were differently expressed in broilers with high feed efficiency and low feed efficiency. Of 124 metabolites, only 44 metabolites had high negative or positive correlation and among those 14, only 14 metabolites is known to have higher heritability. Consequently, they suggested use of 7-ketocholesterol, dimethyl sulfone, epsilon-(gamma-glutamyl)-lysine, gamma-glutamyl tyrosine, 2-oxoadipic acid, L-homoarginine, testosterone, adenosine 5'-monophosphate, adrenic acid, and calcitriol as the potential biomarkers for breeding the "food-saving broilers". Similarly, in dairy and beef cattle, biomarkers associated with feed efficiency are studied and observed to have differential expression in high RFI/feed efficient cattle (Clemmons *et al.,* 2020; Wang and Kadarmideen, 2019). For instance, Chemmons *et al.* (2020) observed eight rumen metabolites positively corelated with higher feed efficiency, involved in lipid and amino acid metabolism such as, 3,4-dihydroxyphenylacetate, 4-pyridoxate, citraconate, hypoxanthine, succinate/methylmalonate, thymine, uracil, and xylose. Metabolomics allows for a more detailed understanding of how animals utilize different nutrients.

Methane Emission:

Methane is an important greenhouse gas contributing significantly to global warming. Compared to carbon dioxide, methane is widely known to have higher (nearly 21 times) global warming potential. The enteric fermentation from ruminants is a major source of methane emissions from ruminants and is dependent on genetic and environmental factors such as breed, genetic makeup, diet, management practices, and physiological status. These factors are moderated for lowering the methane emissions from ruminants. Although microbiology of methane production is widely studied, further research by employing metagenomics and/or metabolomics approach has paved way for comprehensive solutions (Asselstine *et al.,* 2021). Methane emission from ruminants involves costly infrastructure, machinery and is tedious to perform; wherein, metabolome analysis may lower the cost involved in knowing low- or high- methane producing cattle. An interesting study by Yanibada *et al*. (2020) reported that there are significant metabolic changes in hosts emitting less methane compared to hosts emitting more methane. Herein, they employed both targeted and non-targeted metabolomic approach and observed 48 metabolites, primarily of microbial origin (e.g. stachydrine, formic acid, dimethylsulfone), are corelated with methanogenesis and can be used as potential biomarkers. In this regard, Asselstine *et al*. (2021) conducted a systematic review and indicated that integration of information at different levels by employing system biology approach will aid in understanding the underlying genetic mechanisms and metabolism of methane production. Evaluation of metabolome for knowing less methane emitting breeds or individual ruminants, can be of great help in breeding purposes which otherwise involves huge cost. Furthermore, lowering of methane emission may indirectly improve feed efficiency and production performance (Bhatt *et al.,* 2021).

Gut Health and Microbiome Interactions:

The gut microbiome plays a crucial role in animal health and nutrition. Lately, the research focus has shifted towards understanding the gut microbiome and its relationship with various body functions, including cognitive ability in companion animals and humans instead of mere production performance in livestock. To know the gut microbial profile, metagenomics is widely used which helps in identification, characterization and quantification. Besides, metabolomics coupled with metagenomics has been instrumental in elucidating the complex interactions between diet, gut microbiota, and host metabolism (Quin *et al.,* 2023; Wang *et al.,* 2024). In broilers chickens, the administration of probiotic bacteria i.e. Lactobacillus plantarum is reported to alter the gut metabolome and metabolic pathways, particularly inflammatory regulators, mineral absorption, and oxidative phosphorylation (Wang *et al.,* 2024). Similarly, in meat ducks, an integrated approach of metabolomics and metagenomics revealed that, supplementation of resistant starch resulted in enhanced proportion of Firmicutes and butyrate-producing bacteria, and significant alteration in metabolic profile (Quin *et al.,* 2023). Herein, they observed increased level of mucin, butyrate, and epidermal growth factor in resistant starch supplemented ducks.

Novel Feed Additives:

Considering the increasing demand of animal origin food products with limited supply of feed and fodders, there is pressing need of efficient utilization of available feed resources. Accordingly, newer feed additives are explored for improving feed efficiency and reducing the usage of in feed antibiotics. While using newer feed additives, it may come with limitations that will affect the health, reproduction and production of livestock in the long run. To address this issue, metabolomics is being used to evaluate the efficacy of novel feed additives and supplements. Xiao *et al.* (2024) utilized a metabolomics approach to assess the effects of fermented herbal dietary feed additive in piglets, revealing improvements lactic acid and propionic acid, and improved health status as indicated by lowered incidence of coughing and diarrhea. Similarly, Zou *et al. (2022) evaluated the effect of fermented Chinese medicine (rich in bioactive compounds) in* piglets and observed an improvement in milk quality and significant increase in number of metabolites in plasma and milk.

Precision Nutrition:

A new dimension of metabolomics in animal nutrition can be its integration with precision nutrition. By integrating metabolomics data with other omics technologies (e.g., genomics, transcriptomics), researchers can exploit the precision nutrition strategies tailored to individual animals or specific genetic lines.

Metabonomic in Animal Health:

The health of animals is of paramount importance to all the animal husbandry practices for achieving desired productivity and profitability. Infectious and non-infectious diseases in livestock pose significant production and economic losses. Therefore, strategies for prevention, early diagnosis, and treatment of these diseases condition are continuously studied. Prevention of infectious diseases is primarily addressed by vaccination of the animals in endemic areas. However, genetic drift and shift of the virus induce serious complications despite vaccinations. Herein, early and rapid diagnosis of disease condition may help in reducing further losses. In the realm of animal health, metabolomics has proven to be a valuable tool for various applications.

Disease Diagnosis and Prognosis:

As mentioned, metabolome is dynamic in nature and is affected by the physiological status of animals. The metabolome is altered by the perturbations in health of individual animals. Metabolic profiling may help in understanding distinctive patterns associated with different diseases well before manifestation of clinical symptoms. Ketosis, a metabolic disorder commonly found in high producing cattle, has significant impact on milk production, quality and reproduction. Dietary management of peripartum cattle is of prime importance to address ketosis; however, in some instances dietary management fails and early and diagnosis comes into play. On this line, Hunag *et al.* (2024) observed marked alteration in milk and plasma metabolome of dairy cattle experiencing subclinical and clinical ketosis. Herein, they observed plasma glycerophospholipids, pyrimidine, tryptophan, sphingolipid, and amino sugar metabolism. Basoglu *et al.* (2016) identified specific serum metabolites as potential biomarkers for pregnancy toxemia in ewes. Also, the metabonomics of infectious diseases (e.g. Mycobacterium avium subsp. Paratuberculosis) challenged HF cattle and revealed that nearly 25 plasma metabolites are altered. Mastitis is the foremost reason for loss of productivity in high yielding cattle and its early and rapid diagnosis can be crucial in lowering these losses. California mastitis test, commonly used test has less specificity as it shows false negative results in many of the physiological conditions.

Consequently, metabonomics of mastitis cows may help in identifying the metabolites associated with subclinical mastitis. This in turn may be used for developing rapid diagnosis kits. Recently, Zhu *et al.* (2021) employed an untargeted ^{1}H metabolomic approach to evaluate the milk and plasma metabolome of mastitis cows. Herein, they observed significant increases in milk lactate, pyruvate, ethanol, choline, and propylene glycol with reduction in the level of milk 2-oxo-glutarate, carnitine, dimethyl sulfone, and trimethylamine N-oxide.

Stress and Welfare Assessment:

Awareness among consumers and demand for animal products from stress free livestock and poultry is continuously increasing. Besides, consumers have preference towards eggs, meat, and milk produced at farm where all the animal welfare practices are carried out. Assessment of animal welfare through evaluation of stress biomarkers has been continuously followed. In this regard, fecal cortisol level and serum cortisol, MDA level are estimated for knowing the animal welfare and stress conditions in which animals are reared. Metabolomics can provide objective measures of animal stress and welfare. Cheng *et al.* (2016) used metabolomics to evaluate the effects of transport stress on beef cattle, identifying several metabolites as potential stress indicators.

Drug Efficacy and Toxicity:

Like feed additives, newer drugs are discovered, and they need to be evaluated for any harmful effect on vital body functions. Besides, some drugs may not exhibit side effects as symptoms, but they may have negative effects at cellular level and which in the long run may have deleterious effect. Herein, metabolomics can be used to assess the efficacy and probable side effects of drugs. Martínez-Sena *et al.* (2023) employed a metabolomics approach to investigate the hepatotoxicity of various drugs under in vitro condition, identifying key metabolic pathways affected by the drugs.

Challenges and Future Directions:

Despite huge potential, application of metabolomics have several challenges which needs to be addressed.

- Large and complex data: The huge amount of data generated during these high throughput metabolomics techniques requires sophisticated bioinformatics tools and expertise for proper analysis and interpretation.

- Standardization of procedures: Being growing and new filed, there is a pressing need for standardization of protocols at all the levels of processing (that includes sample collection, preparation, and analysis) to ensure high reproducibility.
- Integration with other -omics techniques: Metabolomics alone may not give holistic information about the ongoings or dynamic nature of individuals physiological state. Wherein, the full potential can be realized only through integration with other omics technologies (i.e. transcriptomics, proteomics, metagenomics), requiring advanced computational methods.
- Translation to Practice: Although metabolomics can aid in the development of diagnostic kits and breeding purposes, there are limited studies which has resulted into its practical applications in animal production.

Future directions:

- Development of rapid, on-farm metabolic profiling tools for evaluating animal health and nutrition.
- Longitudinal studies evaluate metabolic changes in animals throughout life cycle to understand the developmental processes and long-term health outcomes.
- The high value information from metabolomics could aid in genetic selection and breeding programs for improved animal health and productivity.
- Development of rapid, low cost, specific, and on-farm diagnostic kits for diagnosis of disease conditions which may enhance the profitability of livestock business.

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Chapter-6

Role of Probiotics for Animal Health and Productivity

Vinod Kumar, Ram Dev Yadav and Mokshata Gupta

Department of Animal Nutrition

College of Veterinary Science and Animal Husbandry, DUVASU, Mathura

Email: vinodsidhu@rediffmail.com

The word "probiotics" was initially coined by Lilly and Stillwell (1965) to refer to growth promoting substances produced by microorganisms. Probiotics are living microorganisms mostly utilized to regulate the microflora of the gastrointestinal tract in organisms. This, in turn, has advantageous impacts on their hosts, such as boosting health and growth (Valdes *et al*., 2018). According to FAO/WHO, probiotics are living bacteria that, when given in appropriate quantities, provide health advantages to the host. Probiotics are considered generally recognized as safe (GRAS) because they provide a natural method for preventing harmful bacteria that can lead to microbial diseases (Markowiak and Slizewska, 2017). Probiotics consist primarily of beneficial bacteria and yeast that destroy harmful bacteria through various molecular pathways, enhance the immune system, and restore the balance of microorganisms in the gut. Lactic acid bacteria (LAB) are mostly employed as commercial probiotics for enhancing animal health. LAB bacteria are gram-positive, facultative aerobic or anaerobic cocci or rod-shaped bacteria. Their primary metabolic end product of carbohydrate fermentation is lactic acid. Additionally, they aid in the digestion of food, resulting in the production of hydrogen peroxide, lactic acid, and other compounds that produce an acidic and inhospitable environment for hazardous or disease-causing microbes.

Lactic acid bacteria are widely considered safe since they are commonly found in food and play a beneficial role in the natural microbial communities of animals and humans. LAB, known for their advantageous and non-disease-causing properties, is regarded as promising probiotics. Lactobacilli and bifidobacteria are the most commonly utilized bacteria for probiotic purposes. Lactobacillus reuteri is a thoroughly studied species of probiotic found primarily in gram-positive bacteria inside the gastrointestinal microbiota of animals and birds (Bhogoju et al., 2018). The utilization of the Streptomyces genus as probiotics has been shown in the field of aquaculture (Augustine *et al.,* 2015). Modes of Action of Probiotics Probiotics exert their beneficial effects in various ways. They can inhibit and regulate intestinal infections while also improving the production performance of animals. The key mechanisms by which probiotics operate include competitive exclusion, strengthening the intestinal barrier by increasing the production of mucin and tight junction proteins, secreting antimicrobial compounds, and modulating the immune system (Raheem *et al.,* 2021). Following is possible mechanism of action of probiotics microbes:

1. Effect on Intestinal Barriers:

The gut epithelium plays a fundamental role in both nutrient absorption and immunological defense. It is tasked with the absorption of 2 essential nutrients, mediating communication between commensal microorganisms, and acting as a barrier against pathogenic bacteria (Chung *et al*., 2012). Thus, epithelium functions as a critical defensive structure by ensuring the integrity of mechanical, chemical, immunological, and microbial barriers. However, the efficacy of these barriers may be compromised in cases where the mucosa undergoes structural disruption or dysregulation (Vancamelbeke & Vermeire, 2017). The administration of probiotics is a potentially effective strategy for augmenting mucosal barrier function, thereby conferring enhanced resistance against pathogenic microorganisms. The intestinal epithelial cells, along with intercellular junction complexes, constitute the mechanical barrier, with tight junctions at the apical region of the intestinal epithelium playing a pivotal role in the regulation of paracellular permeability for small molecules and ions. This regulatory mechanism is essential for preserving the structural and functional integrity of the intestinal barrier, particularly in the exclusion of pathogenic bacteria and toxic substances (Gou *et al*., 2022). Probiotics have been demonstrated to bolster the integrity of the gut barrier by upregulating the expression of genes and proteins implicated in tight junction signaling. Additionally, probiotics modulate the processes of programmed cell death (apoptosis) and proliferation of epithelial cells lining the intestine. For example, Lactobacillus acidophilus has been shown to induce rapid and targeted enhancement of tight junction barrier function within the intestinal epithelium via the activation of Tolllike receptor 2 (TLR-2) heterodimeric complexes, specifically TLR-2/TLR-1 and TLR2/TLR-6, thus offering protection against intestinal inflammation (Al-Sadi *et al*., 2021). Furthermore, goblet cells in the intestinal epithelium secrete a high-molecular-weight glycoprotein, which contributes to the formation of a mucus layer with multifaceted roles, including enhancing nutrient absorption, providing adhesive sites for commensal bacteria, and preventing microbial translocation. Probiotics can stimulate the production of mucin and the secretion of mucus from goblet cells (Gou et al., 2022). In a specific study, treating mucus-secreting colon epithelial cells (HT29-MTX) with supernatants from a probiotic yogurt blend resulted in an upregulation of MUC2 and CDX2 expression, along with enhanced mucin protein synthesis. The yogurt contained Streptococcus thermophilus, Lactobacillus bulgaricus, Bifidobacterium bifidum, Lactobacillus acidophilus, and Lactobacillus gasseri. MUC2 is a key component of the mucus layer, while CDX2 regulates MUC2 production (Chang *et al.,* 2021). In addition, the administration of probiotics to calves has been associated with improvements in growth and development, facilitated by the restoration of gut epithelial integrity and the maintenance of intestinal barrier function (Karamzadeh-Dehaghani *et al*., 2021).

2. Secretion of Antimicrobial Peptides:

Probiotic bacteria are capable of producing a range of antimicrobial compounds, including organic acids (Chang *et al.,* 2021), diacetyl (Kim *et al.,* 2021), hydrogen peroxide (Tomas *et al.,* 2004), and bioactive peptides (Romero Luna *et al.,* 2022), all of which exhibit activity against various microbial strains present in the gastrointestinal tract. Among these, bacterial antimicrobial peptides, commonly referred to as bacteriocins, represent a heterogeneous group of ribosomally synthesized peptides produced by bacteria and archaea (Reuben and Torres, 2024). Bacteriocins function by directly killing or inhibiting the growth of pathogenic bacteria, many of which are implicated in the development of antibiotic resistance through diverse 3 mechanisms (Xuan *et al.,* 2023). Bacteriocins are generally classified into three groups: Class I bacteriocins: These are heat-stable lantibiotics characterized by polycyclic thioether amino acids, such as lanthionine. They are further subdivided into linear (Alantibiotics) or globular (B-lantibiotics) structures. Class II bacteriocins: These heat-stable peptides lack lanthionine and have a molecular weight of less than 10 kDa. Class III bacteriocins: These are heat-labile bacteriocins with molecular weights exceeding 30kDa (Negash & Tsehai, 2012). The antimicrobial activity of bacteriocins is structure-dependent (e.g., based on their amino acid sequence and net charge) and includes mechanisms such as pore formation, enzyme activity modulation, and quorum sensing, which allows bacteria to regulate gene expression in response to population density (Bharti *et al.,* 2015). Class I bacteriocins exert cytotoxic effects by disrupting cell membrane integrity or inhibiting cell wall synthesis. For instance, nisin, an antimicrobial peptide (AMP), interacts with membrane-bound lipid II, leading to pore formation in the bacterial membrane and subsequent lysis (Brotz *et al.,* 1998; Panina *et al.,* 2021). Nisin is produced by Lactococcus lactis and belongs to the A-lantibiotic subgroup, characterized by a positive charge. Another example is mersacidin, a class I B-lantibiotic produced by Bacillus species, which has a globular shape and neutral or negative charge and functions by inhibiting cell wall biosynthesis (Wang *et al.,* 2020). Class II bacteriocins, such as pediocin from Pediococcus pentosaceus GS4 (MTCC 12683), depolarize bacterial cell membranes by binding to receptors like mannose phosphotransferase systems. Pediocin has been shown to exhibit antibacterial activity against pathogens such as Staphylococcus aureus (ATCC 25923), Escherichia coli (ATCC 25922), Pseudomonas aeruginosa (ATCC 25619), and Listeria monocytogenes (ATCC 15313) (Gosh *et al.,* 2019). Class III bacteriocins, such as colicin, megacin, klebicin, helveticin I, and enterolysin, produced by bacteria including Bacillus megaterium, Klebsiella pneumoniae, Lactobacillus helveticus, and Enterococcus faecalis, respectively, act by catalyzing cell wall hydrolysis, leading to bacterial cell death (Bharti *et al*., 2015).

3. Modulation of Host Immune System:

Probiotics play a crucial role in maintaining a delicate balance between essential and excessive defensive mechanisms, involving both innate and adaptive immune responses (Yan and Polk, 2011). These beneficial microorganisms enhance their immunomodulatory effects by promoting the proliferation of favorable microbial populations within the gastrointestinal tract. As highlighted by Zambori *et al*. (2014), probiotics can foster improved nutritional and environmental proto-cooperation by restoring the natural ecological balance, which enables the body to effectively manage both specific and general immune responses. Innate immunity, the body's first line of defense, comprises physical and chemical barriers, such as the skin and mucous membranes, along with immune cells like dendritic cells, macrophages, monocytes, neutrophils, and natural killer cells. Additionally, it involves the release of immunomodulatory cytokines. On the other hand, adaptive immunity, driven by lymphocytes (B and T cells), targets specific threats through antibody production, immunoglobulin synthesis, and cell-mediated responses (Mazziotta *et al.,* 2023). Probiotics modulate innate immunity by enhancing the cytotoxic activity of natural killer (NK) cells and increasing the phagocytic function of macrophages. They also regulate the adaptive immune response by interacting with various immune cells in the intestines, 4 including enterocytes, dendritic cells, and regulatory T cells (Azad *et al*., 2018). Furthermore, probiotics influence host defense systems through multiple mechanisms, such as stimulating phagocyte activity, maintaining a balance between pro-inflammatory and anti-inflammatory cytokines, and promoting the synthesis of cytokines and immunoglobulin IgA (Rabetafika *et al*., 2023).

Effect of Probiotics on Animal Performance:

Probiotics offer numerous benefits to animal performance by enhancing gut health and maintaining microbial homeostasis, which, in turn, optimizes feed conversion efficiency and digestion. This improvement in nutrient utilization can result in increased milk and meat production. Additionally, probiotics are effective in addressing gastrointestinal disorders such as diarrhea caused by stress, antibiotic treatments, or inflammatory bowel disease. Probiotics also play a key role in enhancing immune function, helping to protect the host from various diseases. Furthermore, they can mitigate stress-related physiological responses, such as elevated cortisol levels, which often arise from weaning, transportation, or adverse environmental conditions. By promoting better nutrient absorption, probiotics contribute to improved growth rates. While commonly used in animals such as cats, dogs, horses, and rabbits, probiotics are particularly beneficial for non-ruminant species, offering significant health and performance advantages.

Role of Probiotics in Ruminant Nutrition:

Microorganisms in the rumen play a pivotal role in breaking down polysaccharides and proteins, leading to the production of short-chain fatty acids (SCFAs). Common probiotics used in ruminants include Saccharomyces cerevisiae, lactic acid bacteria (LAB), Aspergillus oryzae, Bacillus, and Enterococcus. These probiotics have been shown to enhance milk production in dairy animals. For instance, probiotic strains such as Bacillus subtilis, Saccharomyces cerevisiae, and Enterococcus faecalis have demonstrated the capacity to boost milk yield (Ma *et al*., 2020). Additionally, Bifidobacterium bifidum has been found to prevent milk allergies (Jing *et al*., 2020). The addition of Enterococcus faecium and Saccharomyces cerevisiae to the diet has been shown to improve the consumption of solid food and further increase milk production (Zhang *et al.,* 2024). The effects of feeding Saccharomyces cerevisiae are influenced by various factors, including yeast strain, dosage, meal composition, lactation stage, and experimental conditions (Amin and Mao, 2021). The diverse bacterial populations in the rumen are essential for enhancing the efficiency of nutrient utilization from feed and impacting milk composition. The diversity and abundance of bacteria in the rumen contribute to the production of key fermentation products such as volatile fatty acids (VFAs), amino acids, and glucose (Zhang *et al.,* 2024). Additionally, rumen fermentation and feed intake influence milk components, including fat, protein, lactose, and minerals (Lucey *et al.,* 2017). According to De Ondarza *et al.* (2010), probiotics can enhance weight gain in ruminants by modifying nutrient utilization, increasing nitrogen retention, and reducing the excretion of essential nutrients. This results in improved feed efficiency, highlighting a more effective use of available nutrients (Khalid *et al.,* 2011). Specifically, Bacillus subtilis and Bacillus amyloliquefaciens have been shown to promote intestinal maturation and growth potential by stimulating the secretion of growth hormone 5 (GH) and insulin-like growth factor 1 (IGF-1) (Du *et al.,* 2018). Probiotics also improve the immune system in ruminants. For example, Signorini *et al.* (2012) reported that administering Lactobacillus acidophilus, Lactobacillus salivarius, and Lactobacillus plantarum at concentrations of 107–108 CFU/g reduces the incidence of diarrhea in calves. Additionally, the use of Lactobacillus-based teat sprays has been shown to improve mammary gland health and strengthen the function of the teat sphincter (Alawneh *et al.,* 2020). Supplementing probiotics in cows not only helps to reduce rumen acidity but also enhances the immune function of young, stressed calves (Krehbiel *et al*., 2003). Various probiotics produce antibacterial substances that can diminish the presence of zoonotic pathogens and modulate ammonia synthesis. Rhodopseudomonas palustris, a photosynthetic bacterium, has emerged as a promising probiotic for animal feed, demonstrating its ability to support rumen microbial populations. The introduction of Rhodopseudomonas palustris enhances the growth performance of rumen microbes and stimulates microbial fermentation, thereby contributing to microbial balance (Chen *et al*., 2020). Similarly, the use of Megasphaera elsdenii can increase butyrate production and improve feed intake in newborn calves (Muya *et al.,* 2015). Furthermore, administering a multistrain probiotic formulation—comprising Enterococcus faecium, Bifidobacterium bifidum, Lactobacillus acidophilus, Streptococcus thermophilus, Lactobacillus rhamnosus, Lactobacillus bulgaricus, and Lactobacillus plantarum during late gestation and early lactation has been shown to enhance milk production, fecal microbial composition, and overall health of dairy cows (Ayyat *et al*., 2024).

Role of Probiotics in Monogastric Animals:

Probiotics have demonstrated significant benefits for the gastrointestinal microbial environment of monogastric animals, including poultry, pigs, veal calves, and equines. These microorganisms enhance growth performance and effectively manage enteric infections such as Salmonellosis, coccidiosis, and necrotic enteritis in broiler chickens (Sedaq *et al*., 2015). For example, Panda *et al.* (2008) found that the inclusion of lactic acid bacteria, bacillus spores, and yeast in poultry diets increased egg production and reduced yolk cholesterol levels. Similarly, Guo *et al*. (2006) reported that the Bacillus subtilis strain MA139 significantly improved feed conversion ratios in chickens. In swine, the addition of Enterococcus faecium to sow diets has been shown to enhance feed intake and reproductive success (Bohmer *et al.,* 2006). Moreover, Le Bon *et al.* (2010) observed a significant reduction in E. coli populations in weaned pigs treated with Pediococcus acidilactici and Saccharomyces boulardii over a four-week period. In equines, the administration of Saccharomyces cerevisiae has been associated with improved rates of apparent nutritional digestion (Agazzi *et al.,* 2011). Probiotics also offer health benefits in humans; for instance, Pessi *et al.* (2000) demonstrated that probiotics can increase the production of antiinflammatory cytokines, such as interleukin-10, in children with atopic conditions. Additionally, Bruzzesse *et al.* (2014) found that treatment with Lactobacillus GG led to a reduction in pneumonia severity in children with cystic fibrosis. Recent research by Horyanto *et al.* (2024) indicated that a probiotic solution containing multiple strains of Bacillus 6 bacteria improved broiler production performance and modified the microbial composition of the stomach during a leaky gut challenge induced by dexamethasone.

Antibiotic Resistance Propagation through Probiotics:

Probiotics, which confer a variety of health benefits, are commonly found in dairy products such as yogurt, cheese, and milk, as well as in dietary supplements (Homayouni *et al.,* 2012; Nagpal *et al.,* 2012). Their inclusion in animal feeds has also been facilitated their transfer to the human gastrointestinal tract through the food chain (Sharma *et al.,* 2014). Despite their numerous advantages, concerns about the potential long-term risks associated with consuming probiotics or probiotic-enriched foods are increasing. These concerns, which have not been thoroughly addressed, create a paradox regarding their use. Probiotics are associated with several safety issues, including the risks of diseases such as bacteremia or endocarditis, potential toxic or adverse metabolic effects on the gastrointestinal tract, and the possibility of transferring antibiotic-resistant determinants to the human gut (Snydman, 2008; Broaders *et al.,* 2013). In Europe, there is awareness of the risk that antimicrobial resistance (AMR) genes might be transferred to the gut microbiota through probiotic use. The European Food Safety Authority stipulates that probiotics can only be deemed safe for human and animal consumption if it can be demonstrated that they do not possess any transferable resistance characteristics. Commercially available probiotics have been found to carry genes associated with antimicrobial resistance (AMR). A recent study identified a transferable vancomycin resistance gene (vanA) in probiotics marketed for animal use. Probiotics, similar to pathogenic bacteria, can be categorized based on their resistance to antibiotics as either "intrinsic" or "acquired." Intrinsic resistance refers to a bacterial species' inherent ability to withstand the effects of antibiotics, which is beneficial as it allows probiotics to restore the natural gut microbiota after antibiotic treatment. Conversely, acquired resistance arises when a bacterial species either undergoes genetic mutations or acquires resistance genes through horizontal gene transfer from other bacteria (Wong *et al*., 2015).

Intrinsic resistance is a genetically determined characteristic primarily linked to specific chromosomal genes and cannot be transferred between bacterial species. An illustrative example of intrinsic resistance is observed in Enterococcus, Lactobacillus, and Bifidobacterium species, which exhibit resistance to vancomycin. Vancomycin acts by inhibiting the synthesis of peptidoglycan, a crucial component of the cell wall in Gram positive bacteria (Jose *et al.,* 2015). Certain bacteria demonstrate specific resistance patterns: Lactobacillus is resistant to metronidazole and nalidixic acid, Bifidobacterium exhibits resistance to metronidazole, norfloxacin, polymyxin B, and nalidixic acid, Lactococcuslactis shows resistance to norfloxacin and polymyxin B, and Streptococcus thermophilus is resistant to neomycin (Jose *et al.,* 2015). In contrast, acquired resistance develops when bacteria gain resistance through gene mutations or horizontal gene transfer due to selective pressure (Hawkey, 1998). This type of resistance often arises from the frequent or prolonged use of a single class of antibiotics. Genetic mutations or the acquisition of resistance genes from external sources can alter bacterial structure or function, leading to diminished sensitivity to related antibiotics. Unlike intrinsic resistance, acquired resistance can be transferred to other bacteria, posing a significant risk. Recent research by Kanimozhi and Sukumar (2024) 7 highlights the potential threat posed by antibiotic-resistant Lactobacilli isolated from egg yolk (deutoplasm). The study found that high consumption of antibiotic-resistant Lactobacilli could facilitate the transfer of resistance genes to intestinal bacteria. This gene transfer may pose a risk to human health, as Lactobacilli could become reservoirs for antibiotic resistance genes.

Next Generation Probiotics:

Recent advancements in gut microbiome research have identified several promising nextgeneration probiotics (NGPs) such as Eubacterium hallii, Faecalibacterium prausnitzii, Roseburiam spp., Akkermansia muciniphila, and Bacteroides fragilis. These probiotics play a crucial role in influencing the development of various diseases when present in the gut. NGPs have been shown to boost the immune system within the gastrointestinal tract, enhance the effectiveness of cancer immunotherapy, maintain intestinal barrier integrity, produce beneficial metabolites—especially short-chain fatty acids (SCFAs)—and reduce the side effects of chemotherapy and radiotherapy (Al-Fakhrany and Elekhn awy, 2024). The specific strain or formulation of NGPs determines their mechanism of action on gut health, immune function, and overall health. They produce valuable substances such as SCFAs and lactic acid, while also stimulating the production of antimicrobial peptides, including lactobinA, curvacin A, enterocin, and pediocin, within the gastrointestinal tract. These peptides play a key role in protecting against harmful bacteria and promoting a balanced gut microbiota by eliminating pathogenic microorganisms and enhancing immune responses (Mandal *et al*., 2014). Moreover, NGPs have the ability to regulate bile acid synthesis and release, which is critical for lipid metabolism and acts as signaling molecules in metabolic pathways. Disrupted bile acid metabolism has been linked to various metabolic and inflammatory diseases, making NGPs an attractive therapeutic option (Sanchez *et al*., 2022). Faecalibacterium prausnitzii has been shown to stimulate the production of the anti-inflammatory cytokine IL-10 in peripheral blood mononuclear cells, likely due to its production of SCFAs, especially butyrate (Martin *et al.,* 2017). This bacterium is associated with microbial dysbiosis, an imbalance in gut microbiota linked to metabolic disorders and chronic immune-mediated conditions such as inflammatory diseases and obesity (DíazRizzolo *et al*., 2020). F. prausnitzii is also being studied as a regulator in cancer immunotherapy (Ennamorati *et al.,* 2020). Akkermansia muciniphila, which forms a symbiotic relationship with the mucosal layer of the human intestine, plays a key role in improving metabolic and immune functions. It has also demonstrated potential in enhancing cancer therapies (Hold *et al.,* 2023). This probiotic is considered a target for treating microbiome-related conditions like cancer, metabolic syndrome, colitis, and immunological disorders (Wagner *et al.,* 2016). Bacteroides fragilis strains, particularly those that produce polysaccharide A (PsA) and outer membrane vesicles, offer therapeutic potential by enhancing adaptive immunity, reducing inflammation, supporting immune system development, and maintaining gut microbiota balance (Wagner *et al*., 2016). Both B. fragilis and PsA are being explored for treating autoimmune disorders and inflammatory bowel disease (IBD). In cancer patients, B. fragilis has shown beneficial effects, including enhancing immune function, reducing lipopolysaccharide (LPS)-related signaling, improving 8 gut flora activity, and preventing leaky gut by maintaining intestinal barrier homeostasis. Eubacterium hallii is known for metabolizing butyric acid, which activates the G-coupling protein receptor signaling pathway, leading to improved production of glucagon-like peptides (GLP1 and GLP2) and strengthening intestinal barrier function. Additionally, it enhances insulin sensitivity and energy metabolism without affecting body weight or food consumption, indicating its potential as a safe and effective therapy for improving insulin sensitivity (Maguire and Maguire, 2017). Roseburia intestinalis has been studied for its production of flagellin, which significantly improves intestinal epithelial integrity in mouse models of alcoholic fatty liver and colitis, suggesting its therapeutic potential for intestinal disorders (Seo *et al*., 2020; Wu *et al.,* 2020). Prevotella copri has shown promise in enhancing glucose tolerance and increasing liver glycogen levels, making it a viable target for managing metabolic diseases such as type-II diabetes and obesity (Alotaibi *et al*., 2022; Lin *et al.,* 2019). Parabacteroides goldsteinii has demonstrated anti-inflammatory and insulinstimulating properties (Alotaibi *et al*., 2022), while Clostridium butyricum plays a key role in maintaining colon health, promoting intestinal cell growth, and even exhibiting anti-tumour effects. It has also shown potential in improving depression when used in conjunction with antidepressants (Miyaoka *et al.,* 2018; Fakruddin *et al.,* 2017). These findings highlight the broad therapeutic potential of NGPs in addressing various health challenges.

Conclusion:

Current research about the role of the healthy microbiome in the maintenance of health and immunity is being explored. This has initiated the development of several other next-generation probiotics, the consumption of such probiotics have a positive impact on the body owing to the microbiota diverse effect. Traditional used microbes, which are mostly lactobacilli and bifidobacteria, are increasingly giving way to next generation probiotics from other families. In the future, more study into the mechanisms of action of these NGPs will allow probiotics to be used as biotherapeutics in the treatment of various life style ailments in human beings and may be used as tools for increasing health benefits in animals and their productivity. A couscous approach into the spread of antimicrobial resistance genes through use of microbes as probiotics is worth investigation.

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Chapter-7

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

R.K. Dhuria
Department of Animal Nutrition
College of Veterinary and Animal Sciences,
Rajasthan University of Veterinary and Animal Sciences, Bikaner
Email: dhuriark12@gmail.com

Livestock production plays an important role in meeting global food demand, providing essential nutrients and livelihoods to millions of people worldwide. It is considered as a significant contributor to the world's food supply. Different species of Livestock serves as source of high-quality animal protein and valuable animal by-products. Livestock also contributes to agricultural sustainability by providing manure for fertilization. The expansion of livestock sector offers significant prospects for agricultural development, poverty reduction, food security, and human nutrition. Large-scale livestock production can meet the expanding demand for animal products worldwide. Animal proteins are highly nutritious and form a key part of a balanced diet. The rising demand for animal protein leads to driving up greenhouse gas emissions and pressure on natural resources. In recent years, the livestock production sector has become increasingly unsustainable, leading to clearance of forests to produce land for grazing, over-grazing of existing lands, and increased production of methane and carbon dioxide with resultant environmental consequences. There is a need to implement a more appropriate, sustainable and environment friendly livestock production system to alleviate the livestock production sector. Central to this is finding ways of maximizing the efficiency of current livestock production systems so that all existing resources are used as efficiently as possible. Sustainability is a holistic concept that considers ecological, social, and economic dimensions. Sustainable livestock production promotes the long-term availability of the livestock products, protects natural resources, enhances economic resilience, and contributes to a more sustainable and resilient future. Sustainable animal production aims to increase productivity while reducing environmental impact. This can be achieved through innovations in feed and technology, as well as improved animal health and husbandry practices. Sustainable intensification has emerged as a prominent trend in livestock production and it involves optimizing resource use, improving feed efficiency, reducing greenhouse gas emissions, and minimizing waste. The key points of sustainable animal production include:

- Improving the lifetime performance of farm animals
- Making efficient use of natural resources
- Reducing emissions from livestock
- Helping tackles antimicrobial resistance
- Improving the nutritional quality of meat, milk, fish and eggs while reducing food loss and waste

Nutritional Strategies for Promoting Sustainable Livestock Production:

Automated Feeding Systems:

Automated feeding systems are innovative devices that can improve animal feeding by using automation technology. It provides precise and scheduled feedings, ensuring optimal nutrition to each and every livestock and effective resource management. Automated feeding system revolutionizes the livestock industry by reducing labour cost and improving feed efficiency of livestock. Automated systems dispense and mix feed accurately, ensuring each animal gets the right nutrients and adjusting rations based on real-time data. For example, the use of robotic feeders in dairy farms provide customized feed based on the milk production and health status of the cow while automated systems in poultry farms adjust feed distribution according to the different growth stages of the birds.

Precision Animal Nutrition:

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 by minimizing waste. Precision nutrition is also called "Information Intensive Nutrition" because it uses the latest scientific findings in feed formulation to meet the unique nutrient requirements of a given herd with the maximum accuracy.

Phase Feeding:

Phase feeding involves feeding a number of successive diets, each differing in its protein, energy or amino acid balance to match the evolving nutritional requirements of the animals. Phase feeding can be used for a variety of animals, including pigs, poultry, and beef cattle. The primary goal of phase feeding includes optimizing growth performance of animals as well as reducing nutrient excretion. The feeding of livestock causes the major portion of rearing (About 65-75% in various species of livestock). Thus, any managemental step to reduce the cost of feeding will definitely improves the overall profitability of livestock farming. The feed provided should closely matches the animal's nutrient requirements and minimize the over- and under-feeding of nutrients. With the help of phase feeding, livestock gets the sufficient nutrients to meet their actual nutrient demand and can be prevented from the various deficiency diseases with maximum production.

Novel Feed Ingredients:

Novel feed ingredients are unconventional ingredients used in animal feed that are not typically used by feed manufacturers. They can be derived from plants, animals, or inorganic sources. The use of novel feed ingredients in animal feeding systems serve as a helpful approach for combating the global demand of grains and other existing feed resources. One such ingredient is the insect protein which can be used as an alternative source of protein for poultry, swine, fish, and prawns. Insect protein obtained from black soldier fly larvae (Hermetia illucens) is a rich source of protein, fat and other essential nutrients thus can be used for feeding livestock. Algae and seaweed are also emerging as valuable feed ingredients for livestock due to their high nutritional content, including proteins, lipids, vitamins, and minerals. Single-cell proteins sourced from microorganisms like yeast, bacteria, and fungi, offer a sustainable protein option for livestock.

Feed Additives:

Feed additives including enzymes, antioxidants, growth promotors, and immunomodulators are essential for improving livestock performance and health. Antibiotic Growth Promoters are used to boost growth and prevent disease but now restricted or banned in many places due to antibiotic resistance. As an alternative to antibiotics, probiotics, prebiotics, and bioactive compounds are used to improve gut health and nutrient absorption in animals. In addition, the use of low methane feed additives like seaweed extracts, essential oils and phytogenic supplements helps to reduce the methane emission from ruminants. The approach also helps to mitigate climate change, enhance feed efficiency, and boost animal productivity.

Other Strategies for Promoting Sustainable Livestock Production:

Animal Health and Welfare:

Good animal health and welfare are central to sustainable livestock production as they promote high productivity, adequate animal care and the efficient use of natural resources. Improving animal health will improve public health as healthy animals are less likely to carry and pass on zoonotic food-borne pathogens. Good animal health and welfare can lower greenhouse gas emissions per unit of output. They reduce the need for antimicrobials and protect farmers and consumers from foodborne diseases and other zoonoses.

Disease Management:

Different animal diseases directly and indirectly affect the production of animals and economic status of the livestock owners. Thus, the effective disease control is the key for maintaining animal health and output. Diseases management can be achieved by using latest diagnostic tools, vaccines, antibiotics, and other drugs that can help in prevention and treatment of different animal diseases. Better diagnostics make it possible to detect and treat diseases more quickly and sometimes also directly at the farm. Information and communication technology can be used to ease disease reporting and response. Biosecurity measures can be applied to animal farms to prevent the spread of disease. The biosecurity measures must cover all potential entry points, including animal movements, people and equipment involved in production, as well as feedstuffs.

Genetic Improvement:

Advances in genetics enables to breed animals with traits that can enhance sustainability. Genetic modification is being explored to produce livestock that are more resilient to environmental stress. With the help of selective breeding the genetic traits of livestock can be improved and their productivity can be enhanced. Molecular genetics can be used as an effective tool to identify specific genes responsible for desirable traits hence may allow more targeted breeding programs.

Advanced Breeding Technologies:

Reproductive technology has improved animal health and output during the last century. Artificial insemination and embryo transfer are the techniques that can be used to produce animals with desirable genetic features. Some traditional livestock breeds have valuable genetic traits that confer hardiness and more general disease resistance. It is important to raise these breeds in situ to maintain and further develop these traits, and to conserve their germplasm in gene banks.

Integrated Approaches:

Integrated approaches have been found to support a sustainable increase in animal production. In integrated systems, the output of one process becomes the input of another, and there is minimum nutrient leakage to the environment. The silvopastoral system is one example for such an integrated approach, which combines forestry and grazing of domesticated animals in a mutually beneficial way. Such systems help to reduce the greenhouse gas emissions and the chemical contamination of soil and waterways, while preserving biodiversity by avoiding the use of vehicles, fertilizers and herbicides.

Techniques for Reducing Methane Emission:

Livestock farming, particularly the production of ruminants such as cows and sheep, is responsible for significant methane emissions. The use of High-quality forages, grains, and feed additives such as oils or seaweed can reduce methane emissions. Selective breeding programs are being developed to produce animals with lower methane emissions capacity. Manure is another significant source of methane emissions which can be managed by implementing better manure management practices, such as composting or using anaerobic digesters to produce biogas.

Smart Farming Technologies: S

mart farming technologies for sustainable livestock production include drones, robotics, and AI-enabled systems. These technologies can help improve efficiency, reduce waste, and increase profitability. Smart technologies such as remote sensing and the Internet of Things (IoT) greatly enhance efficiency and productivity of animals. These techniques provide accurate data on animal health and behaviour, enabling early detection of diseases and reduction of waste, thereby improving production quality and profitability, especially in small farms.

Data Analytics and Artificial Intelligence (AI):

In sustainable livestock production, artificial intelligence techniques primarily utilize machine learning algorithms, computer vision, and sensor data analysis to monitor individual animal health, behaviour, and environmental conditions, allowing for optimized feeding, disease detection, resource allocation, and overall improved animal welfare, leading to more sustainable farming practices. Artificial Intelligence is becoming increasingly important in promoting sustainable livestock and poultry farming. AI helps to improve efficiency, productivity, sustainability, and health of animals.

Conclusions:

Livestock production is a dynamic and evolving industry that is influenced by various trends, innovations, and challenges. The current trends in livestock production highlight the importance of sustainable intensification, animal welfare, digitalization, and alternative protein sources. Sustainable livestock production is essential for the environment, food security, and animal welfare. It can be achieved through a combination of technology, planning, and practices that prioritize animal welfare. By embracing these trends and innovations while addressing the challenges, the livestock production industry can work towards a more sustainable, efficient, and responsible future.

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Role of Feed Enzymes to Achieve Improved Animal Nutrition and Health

P.K. Singh, Aakritee Kumari, Pranit Mankhair and Priyanka Kumari
Department of Animal Nutrition
Bihar Animal Sciences University, Patna
Email: vetpank@gmail.com

Introduction:

The demand for animal products has increased due to the population's intense and quick growth, and enzymes are being employed widely to improve animal nutrition and health to meet this demand in an economical way. An enzyme is a naturally occurring protein that functions as a biological catalyst. It quickens a particular chemical reaction occurring within the cell. The enzyme is utilized repeatedly and is not destroyed during the reaction. Enzymes are added to animal feed as "feed additives" to boost production and feed efficiency. Feed additives are materials, microbes, or preparations put to animal water or feed to enhance the animal's health and well-being or the quality of feed itself i.e. to enhance the digestibility of feed materials.

Especially in diets based on wheat or barley, feed enzymes have been widely used in cattle and poultry feed. Today's enzymes are mostly derived from a variety of helpful microbes, though they can also come from plants and animals. Even while animals and their gut flora produce a large number of endogenous enzymes, these enzymes are insufficient to diminish the antinutritional factor of the feed or to aid in the absorption of all the components included in the animal ration. Feed enzymes are the fermented byproducts of bacteria and fungi that appear to benefit animals only inasmuch as they aid in the breakdown of specific feed ingredients like proteins, phytates, and glucans, which the animal may have trouble digesting (Kiarie et al., 2013). The enzymes were produced by microorganisms such as yeasts (Saccharomyces cerevisiae), fungi (*Asperigillus niger, A. oryzae*, and *Triochoderma longibrachiatum*), bacteria (*Bacillus lentus, B. subtilis, B. stearothermophils* and *B. amyloliquifaciens*) (Wallis, 1996).

Significance of Feeding Exogenous Enzymes as Feed Additive:

Exogenous enzyme supplementation improves the digestibility of feed components which are difficult to digest. In several livestock species, especially swine and poultry, exogenous enzymes have been utilized to enhance nutrient consumption. Conversely, the application of exogenous enzymes in ruminant diets has been restricted, mostly due to the belief that ruminal hydrolysis precludes the rumen's ability to hydrolyze more efficiently and the apprehension that such enzymes would be useless (Adesogan, 2005). Cereals like barley, wheat, rye, and triticale include non-starch polysaccharides (NSP) and are mostly utilized in feed industry. These NSP forms very viscous gut content during digestion and are undesirable as they reduce the bioavailability of nutrients like fat and protein specifically (Khattak et. al, 2006). Enzyme reduces the viscosity and increases nutrient bioavailability Ultimately helps in growth promotion. By uplifting the growth of poor performing animals there is better uniformity of animals at the market time.

Increase in the range of feedstuffs increases the flexibility in feed formulation and feed can be cost efficient too.Enhanced feed efficiency lower the dietary concentrations of specific nutrients while simultaneously reducing their excretion and nutrient load (excreta nitrogen and phosphorus levels) into the environment. This can limit the potential for eutrophication and acidification of manure and hence is less harmful for the environment.

According to reports, there are three ways that exogenous enzyme supplementation is effective: 1) by increasing feed conversion efficiency; 2) by releasing nutrients that are trapped in insoluble diet portions; and 3) by releasing oligosaccharides, which support healthy microflora while suppressing harmful bacteria (Paloheimo et al., 2010).

Enzymes used in Poultry:

High-quality meat and eggs can be obtained from domestic poultry. Between 70 and 75 percent of the total cost of production goes toward producing feed, which is primarily made up of grains of cereal (corn, wheat, sorghum, and proteins of vegetable flours) that give the animal energy. However, because these ingredients are expensive, producers and farmers have substituted them with less expensive ingredients like barley, oats, rye, sunflower flour, etc., but these typically contain anti-nutritional factors (ANF) like antigenic components, raffinose oligosaccharides, saponins, protease inhibitors, tannins, lectins, and phytic acid that are indigestible by monogastric animals. ANF can cause the digesta to become more viscous, hinder the absorption of nutrients, and even raise the risk of pathogenic illnesses such necrotic enteritis, which can harm chicken health and raise production costs. Because they lack an enzyme, poultry raised on cereals are unable to hydrolyze the starch-free polysaccharides found in their cell walls (Raza *et al*., 2019).

Enzymes are used for poultry feeding for two purposes mainly i.e. to provide the enzyme which cannot be synthesized by them and to complement the enzyme which is insufficiently produced. starch degrading enzymes, NSP degrading enzymes, Proteases, Phytases and Lipases are some of the enzymes which are being used extensively in poultry.

Starch Degrading Enzymes:

Starch degrading enzyme includes amylase, α-galactosidases e.t.c. Amylase acts on starch and convert starch into sugars upon hydrolysis of 1,4 glycosidic linkage. Its activities support the bird's endogenous amylase secretion, releasing energy to support growth. By making starch easier to digest, glucose is less likely to be present in the latter stages of the gastrointestinal tract as a possible substrate for harmful bacteria. Increased energy output, improved meat and egg yields has been seen from diets supplemented with α-amylases (Ojha et al., 2019) and increased performance from chickens fed a diet of maize and soybeans supplemented with α-amylase has been seen (Garcia *et al.,* 2003).

Alpha-galactosidase is a digestive enzyme that breaks down galacto oligosaccharides (GOS) found in soya bean and other legumes. According to (Amer et al., 2020), broiler chickens fed an energy-reduced diet (−120 kcal/kg compared to the control diet) showed a substantial improvement in their final BWs (40 d) and overall feed conversion ratio (FCR) when α-galactosidase was added at a level of 50 ppm on an SBM- corn-based diet.

NSPs Degrading Enzymes:

Non-starch polysaccharides (NSP) constitute a major part of the dietary fibre component in plant-based feed ingredients and differ in structure and composition from starch. Plant-based components, which include roughly 10–30% non-starch polysaccharides (NSP), make up the majority of a poultry ration (Choct, 2015). Through its effects on gastrointestinal tract development and morphology (Iji P.A., 1999) as well as microbiota population and composition dietary NSP both directly and indirectly influences the nutritional value of the diet and digestion function and metabolic processes.

Complex polysaccharides are broken down by NSP enzymes, which can lower intestinal viscosity and improve the environment for good bacteria. NSP enzymes can improve the efficiency of avian nutrition absorption. Anti- nutritional elements, such as non-starch polysaccharides, might impede the absorption and use of nutrients in feed materials.

NSP enzymes contribute to the feed's total nutritional value by mitigating the detrimental impacts of these variables. Reduced excretion of undigested feed components can be achieved by using NSP enzymes to aid in the efficient digestion and use of nutrients. This reduces the negative effects of trash production on the environment in addition to helping the birds. NSP enzymes are incorporated into chicken feed formulations to help achieve more consistent performance between feed batches. NSP enzyme includes xylanase, β- glucanase and cellulase.

Mechanism of Action:

NSP enzymes dissolve the parts of the cell wall that releases nutrients and are enclosed and lowers the viscosity of the digestive system, which quickens the rate of digestion. The bird's endogenous enzymes have better access to nutrients and the small intestine experiences less bacterial multiplication when these two methods of action are combined.

β- glucanase:

β- glucanase is a group of enzymes which breaks the β-glucanase polysaccharide. The 1,3 and 1,4 links in mixed-linked glucans are broken down by beta-glucanase, which facilitates better digestion of non-starchy polysaccharides found in cereal grains and increases feed conversion ratio. This makes it possible to incorporate more cereals, such as barley and oats, into poultry feed. Adding exogenous β- glucanase to barley-based diets can reduce the digesta viscosity and increase nutrient digestibility, egg production, and feed efficiency in laying hens (Lazaro *et al*., 2003a).

Mode of Action:

β-glucanases break down the 1,4 or 1,3 links presents in mixed-linked glucans, causing the endospermic cell wall's integrity to be compromised and thus maintaining the viscosity of small intestine by breaking high molecular weight NSP into small molecular weight NSP.

Xylanase:

Enzymes known as xylanases are hydrolytic agents that break the polysaccharide Xylan, a complex component of plant cell walls, at its β-1, 4 backbones. Complex polysaccharides like Xylan are broken down into smaller, easier-to-digest bits. A significant part of hemicellulose is the non-starch polysaccharide (NSP) Xylan, which is present in plant cell walls. Corn, wheat, and soybean meal are examples of plant-based feed ingredients that are high in non-starch polysaccharides (NSPs), which include arabinoxylans and are challenging for animals to digest properly. In order to release more simple sugars and other nutrients for the digestive tract to absorb, xylanase aids in the breakdown of these complex NSPs. In addition to increasing feed efficiency, this also lessens the detrimental impacts of NSPs on nutrition, such as increased microbial fermentation and gut viscosity, which can cause digestive problems and poor animal performance. Microorganisms like Trichoderma reesei and Bacillus species are sources of xylanases (Alvarez *et al.,* 2016).

Mode of Action:

Lowers Viscosity: Non-starch polysaccharides (NSPs) are broken down in the upper digestive tract by xylanase, which lowers the viscosity of digesta in the small intestine. By doing this, feed efficiency is increased and NSPs' anti-nutritional effects are lessened.

Releases Nutrients: In order to release more simple sugars and other nutrients for the digestive tract to absorb, xylanase breaks down complex NSPs.

Encourages Bacteria that Break Down Fiber: The large intestine's bacterial population that breaks down fiber may be encouraged to grow by xylanase.

Keeps the Microbiome Healthy: A stable, healthy microbiome can be preserved by xylanase by reducing the nutrients that cecal pathogens can access.

Cellulase:

Poultry do not synthesize the enzyme to hydrolyze fibre completely and depends on exogenous enzyme to aid in the digestion. By breaking down cellulose into easily absorbed carbohydrates like glucose, cellulase enzymes support the natural digestive processes of animals. By increasing the availability of minerals that are trapped within plant material, this enzymatic process helps animals better digest and absorb vital nutrients.

Protease:

Proteases are provided to feed to facilitate better nitrogen utilization by increasing the rate at which dietary proteins are hydrolyzed. Improved nitrogen utilization by animals may lead to a reduction in the amount of protein in their diet, which will also lower the amount of nitrogen in their manure.

Mode of Action:

It catalyzes the breakdown of proteins into smaller polypeptides or individual amino acids, a process known as proteolysis. It improves the optimal assimilation of amino acids and proteins, support gut health and overall performance.

Phytase:

Phytase is an enzyme used in poultry feed which helps to break down Phytate phosphorus which is present in plant-based diets. Phytase lessens the requirement for P supplements by improving the poultry's ability to absorb phosphorus from feed. Since poultry cannot generate the enzyme phytase, birds must receive exogenous phytase in their food. The most often utilized exogenous enzyme in the feed for animals with single stomach is microbial phytase. Phytase can lessen the detrimental effects of inorganic P excretion to the environment, as well as lessen the antinutritional effect of phytate and increase the digestibility of phosphorous, calcium, amino acids, and energy.

Mode of Action:

It facilitates the gradual extraction of phosphate from phytic acid or phytate, its salt. Phytase releases phosphorus and other nutrients that would not otherwise be able to be absorbed by breaking down phytic acid into smaller compounds in a sequential manner. It enhances absorption of nutrients and indirectly boost the use of energy and nitrogen.

Lipases and Emulsifiers:

Triglycerides are broken down by lipases into fatty acids and glycerol by lipases. The growth performance of broilers can be enhanced by the addition of lipase to low energy diets. Supplementing lipases with emulsifiers (bile salts, lysolecithin) increases the active surface area of lipid droplets and promotes the production of micelles for the lipase enzyme's action, thereby improving lipid digestibility. Emulsifiers are essential for improving the absorption and digestion of fat.

Enzymes Used in Ruminants:

Exogenous enzymes provided to ruminants as feed additives. ß- glucanase, xylanase, ß-mannanase, amylolytic and proteolytic enzymes are examples of exogenous enzymes added to animal diets. It is anticipated that these enzymes will improve dietary starch, protein, ß- glucans, arabinoxylans, and mannan utilization and digestion, respectively. These enzymes hydrolyze those feed substrates which are partially broken or not broken down by endogenous enzymes.

As forage contains complexly linked cell wall portions that prevent their breakdown, ruminants usually eat diets high in forage. About 40–70% of the total dry matter (DM) in forages may be made up of insoluble cell walls, which could be broken down by enzyme activity (Van Soest et al., 1994). Major structural polysaccharide in plants are cellulose and hemicellulose. Feed enzymes for ruminants consists of mainly cellulase and hemicellulase activity and mainly produced from the fungus *(Trichoderma longibrachiatum*) and bacterial (Bacillus species). Cellulase includes endo β- 1,4-glucanase and exo- β- 1,4-glucanase which hydrolyses cellulose into cellobiose and cellooligomers. Hemicellulases are β- 1,4-glucosidase, β- 1,4-xylosidase e.t.c. which acts on cellobiose and xylobiose to give glucose and xylose respectively.

Conclusion:

Feed enzymes play a crucial role in improving animal nutrition and health by enhancing the digestibility of feed ingredients. They help break down complex carbohydrates, proteins, and fats, making nutrients more accessible for absorption. This leads to better feed efficiency, improved growth rates, and overall animal performance. Additionally, feed enzymes can reduce anti-nutritional factors, such as phytates and non- starch polysaccharides, which can hinder nutrient utilization. By optimizing nutrient availability, these enzymes also contribute to better gut health and can reduce the incidence of digestive disorders. Overall, the use of feed enzymes supports sustainable animal production by maximizing feed utilization and minimizing waste.

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Chapter-9

Advancements and Future Directions in Poultry Nutrition

Udeybir Singh, Sandeep Uniyal and Amit Sharma
Department of Animal Nutrition
Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana
Email: udeybirchahal@gmail.com

Poultry production, which includes species like chickens, turkeys, ducks, and guinea fowls, is a vital component of global agriculture. The growth and commercialization of this sector have been significantly driven by research advancements in breeding, nutrition, housing management, and disease control. These innovations have led to improved productivity, efficiency, and sustainability, enabling the industry to meet increasing global demand while addressing health and environmental challenges. These research efforts were largely geared towards the following: improving genetic strains specialized for food use (meat and eggs) and regional conditions; improving knowledge of nutritional requirements and ability to match these for variable conditions; and ensuring stable environment for growth and production Nutritional research in poultry has several key objectives: selecting optimal feed ingredients to promote growth, creating conditions that allow birds to reach their genetic potential, combating certain diseases, lowering production costs, maintaining product quality, and mitigating the negative impacts of environmental stressors. These advancements are essential for ensuring that the poultry sector remains a significant contributor to animal protein production, especially as the global population continues to grow. By focusing on these areas, the industry can enhance efficiency, sustainability, and overall resilience in meeting food demands. Poultry meat and eggs are highly valued and consumed in diverse ways around the globe, providing essential protein and micronutrients. They are produced in large quantities, making the poultry sector one of the leading suppliers of meat worldwide. Additionally, poultry products are generally affordable, catering to low-income consumers in both developing and developed nations. The sector has significant growth potential, driven by factors such as population increases, the breeding of high-yield meat and egg strains, rising consumer incomes, and advancements in feed processing and poultry product technologies. However, the cost of feed remains a critical challenge for farmers, influencing profitability and their ability to scale production. Addressing feed costs is essential for maximizing the economic benefits of poultry farming and supporting its continued expansion.

Over the years, researchers have developed and refined new techniques to gather valid data and address the evolving challenges in the poultry sector. In this section, discussion on some key advancements in poultry nutritional research will be done which aimed at enhancing productivity and the quality of meat and eggs, improving bird welfare, and promoting environmental sustainability. These advancements include modern methods for feed analysis and nutritional experimentation that incorporate novel feed ingredients and additives. Innovations such as nano-minerals have emerged, offering improved bioavailability and efficacy in poultry diets. Researchers are also exploring mineral toxicity to ensure safe feeding practices. Additionally, dietary management strategies are being developed to mitigate health issues and environmental impacts associated with poultry production. By focusing on these areas, the poultry sector can continue to thrive while ensuring the well-being of birds and minimizing its ecological footprint.

Advancement in Analysis of Feed:

To effectively meet the nutrient requirements of poultry, it is essential to have a thorough understanding of the nutrient profiles of various feedstuffs. This necessitates comprehensive feed analysis that examines both the nutrient composition and the presence of anti-nutrients. By accurately assessing these factors, nutritionists can formulate balanced diets that optimize growth, health, and productivity while minimizing potential negative effects from anti-nutrients. This knowledge is crucial for ensuring that birds receive the necessary nutrients for optimal performance and well-being. There have been advanced techniques employed over the years which give true reflectionsof chemical composition of feedstuffs that enables nutritionists to be able to accurately formulate diets for all types and classes of poultry. These advancements include refined methods for determining dry matter, protein, carbohydrates (including fiber), fats/oils, and macro- and micro-minerals, as outlined in the official Methods of Analysis (2019) published by the Association of

Analytical Chemists (AOAC) International. These techniques provide a precise analysis of the chemical composition of feedstuffs, enabling nutritionists to formulate accurate diets for various types and classes of poultry.

The use of advanced analytical techniques ensures that the nutritional profiles of feed ingredients are accurately assessed, allowing for better formulation of diets that meet the specific needs of poultry. This precision not only enhances growth and productivity but also supports overall bird health and welfare. Examples are vacuum-oven drying/toluene distillation of high fat feeds for moisture determination; Automatic Kjeldahl Analyzer/Dumas technique (LECO)/Amino Acid Analyzer for protein determination; Megazyme enzyme kit for starch determination in cereals; Rose-Gottlieb/Soxflo method for fat determination; Fibre Analyzers for determination of acid detergent and neutral detergent fibres, and the use of Inductively coupled plasma optical emission spectrometry (ICP-OES) analyzer for determination of several minerals at the same time; Near-infrared spectroscopy (NIRS) technique for determination of moisture, crude protein, metabolizable energy and digestible amino acids of whole feed sample. The presence of anti-nutritional factors (ANFs) in feedstuffs can significantly compromise their nutritional value for poultry and negatively impact bird health. Advances in feed analysis have enabled the identification and quantification of these ANFs, transforming previously inedible plant materials into valuable feed resources.

For example, the identification and removal of trypsin inhibitors in soybeans have markedly improved their feed value for poultry. Various analytical methods have been developed to detect ANFs, including:

- **Yb-precipitation/Vanillin-HCl/DMACA-HCl/BSA/PEG/mass spectrometry** for determining tannins.
- **High-performance liquid chromatography (HPLC), acid-base titration, and acid dye colorimetry** for assessing alkaloids.
- **ELISA methods** for the detection of mycotoxins.

These techniques facilitate a better understanding of the composition of feedstuffs, allowing nutritionists to enhance the overall quality and safety of poultry diets.

Advancement in Ration Formulation:

Ration formulation is crucial in meeting nutrient requirements of poultry. This aims at avoiding excess nutrient supply as much as nutrient deficiency. Advances in this regard are made possible by computer software developers. Prominent among poultry feed formulation software is the Least-Cost formulation software. It is helpful in formulating high-quality diets for different types and classes of birds at a low cost. Generally, feed cost constitutes more than 60- 70 % of poultry production cost. Therefore, use of this advance technique in diet formulation greatly reduces the cost of feeding birds; which may account for affordability of poultry products. The most valuable advance technique in poultry nutrition is the use of the NIRS technology. Apart from accurately predicting the chemical composition of raw feed ingredients and feeds, this technology enables the farmer to rapidly measure metabolizable energy (ME) and digestible amino acid (DAA) in real time (or near real time) for major feed ingredients. ME and DAA are the main dietary components considered in poultry feed formulation. The actual ME and DAA contents of feed ingredients (e.g. different geographical locations or batches) could vary substantially from the specifications setup (matrix) in the feed formulation software leading to formulation errors. This technology is used to enhance precision feed formulation in relation to ME and DAA. The results can be obtained immediately after NIRS scanning of feed ingredients. Although NIRS equipment is expensive, all other costs to implement the technology can be reduced.

Utilization of Feed:

Effective means for dietary feed to be quantified and prepared is to perform studies of digestibility and bird growth efficiency studies. This helps in feed quality assessments. Advances made with respect to determination of feed utilisation are ever-evolving. These include: Growth assay technique, *In vivo and In vitro* digestibility techniques, Inert marker technique, Caecetomy and Ileotomy techniques and Ileal assay technique. The advantages of these techniques among others are high precision data, reduction in duration and cost of experimentation, less labour-intensive, use of small feed samples, avoid use of live birds for experiments, and rapid routine feed quality assessments

Use of Novel Unconventional Feed Ingredients:

Traditionally birds are grain feeders; however, with advent of industrial processing of food for humans, a lot of by-products have been generated and researchextensively for poultry feeding. These include cereals byproducts, oilseed meals, brewer's dried grains, distillers dried grain with solubles (DDGS), gluten meals etc. The essence of using these novel feed ingredients is to serve as alternativesfor conventional feed ingredients such as soybean meal and fishmeal.

This is aimed at reducing feed cost or curtailing dependency on these conventional feeds, particularly in developing economies.

Use of Alternative Growth Promoters:

Concerns over environmental and public health risks associated with the emergence of antibiotic resistance in zoonotic bacterial pathogens due to therapeutic and/or non-therapeutic use of antibiotics have led to global interest in adopting more stringent use of antibiotics in food animal production. In 1986 Sweden banned the use of antibiotic growth promoters (AGPs) and this was followed by a series of events that led to an EU-wide ban that took effect on January 1, 2006. These merging issues for both conventional and organic poultry production pushed the animal nutritionist to find the alternative approaches to improve feed efficiency in the absence of AGP supplementation. One such alternative are probiotics, prebiotics, symbiotics, postbiotics, acidifiers, phtobiotics etc have been identified as effective alternatives to antibiotics. These have been growing in popularity as feed additives, due to their beneficial effect on gut health and immunity and growth performance.

Production of Designer Eggs:

Studies on dietary modification have played a major part in the production of nutritionally-improved eggs referred to as “Designer Eggs”. By way of nutritional manipulations of the cholesterol content and its fractions, lipid profile, fatty acids, amino acids and minerals can be modified to produce healthy eggs for humans. This can also be done through addition of therapeutic pharmaceutical compounds.

Nutritional Management, Gastro-intestinal Tract Conditioning and Poultry Health:

It’s undeniable fact that achievement of productive efficiency can only be attained through nutrition if and only if the health status of birds is not compromised. Therefore, current nutritional researches are geared towards optimizing poultry health and consequently their welfare. Some of these nutritional strategies with positive impact on poultry welfare have been reviewed extensively. They include: manipulation of diet composition (e.g. dietary ME/CP as a way of controlling the body composition to prevent body fatness of market broilers or fatty liver hemorrhagic syndrome in layers); addition of essential fatty acids such as linoleic acid and linolenic acid to prevent lesions or supplemental fats/oils to increase dietary ME values; use of calcium and phosphorus (an approximate ratio of 2: 1), or vitamin D to prevent bone problems such rickets and tibial dyschondroplasia or cartilage abnormalities that can lead to welfare problems such as osteomyelitis and femoral head necrosis; use of major supplemental mineral like sodium/vitamin and trace mineral supplements to boost normal health and/or under adverse conditions; use of feed additives such as enzymes and probiotics discussed above to improve feed efficiency with added advantage of less sticky excreta (better litter quality with less incidence of hock burns) and control of disease causing organisms, respectively; dietary modifications to help birds cope with stress, particularly under hot climatic conditions (e.g. decreasing crude protein content, use of synthetic amino acids to increase amino acid intake, use of fat to help decrease heat increment, use of sodium supplement as bicarbonate for maintenance of blood electrolyte balance, use of vitamins such as vitamins C, E and A to help in heat and other types of stress); and physical manipulation of feed such as mash feeding and feed restriction to control growth for maintenance of good health (e.g. lower mortality, reduction in metabolic disorders, improved walking ability.

Use of Nano-Minerals:

The use of nano-minerals in poultry nutrition is a recent concept that is gaining grounds as a result of varied application of nanotechnology in animal production systems. This has to do with alteration of particle size to few nano meters (1–100 nm) and studies reviewed so far have proved that feeding of nanoparticle improved digestive efficiency, immunity, growth rate, performance, resistance to pathogens, quality of meat and eggs in birds

Conclusions:

Nutritional research has contributed significantly to poultry production over the years. Its role in the poultry sector is more crucial than ever before in sustaining progress made in the sector as world population continues to increase at alarming rate. The progress in nutritional research is made possible by several advanced techniques that have been developed and tested by numerous researchers both in academia and industry. The appropriateness of any techniques to be used depends on the facilities available at the research site and the cost involved. Also, there is a need to maintain balance between research that may have future usefulness (fundamental research) and that which may be used immediately (applied or practical research) through application of scientific innovations. In future, nutrition objectives will require scientists to use extensive interdisciplinary approaches

Future Nutritional Research Focus:

Advances in poultry breeding, emergence of new feed resources, consumer demands and climate change as well as environmental concerns have implications for future poultry nutritional research. Thus, nutritional research focus, henceforth, will be influenced mostly by the following innovations:

- Feed formulation software and feeding programme
- Novel feed ingredients and feed additives
- Gastro-intestinal conditioners for gut health, birds' welfare and food safety
- Modern technologies for feed processing and feeding packages
- Perinatal nutrition and epigenetic programming.

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Chapter-10

Optimizing Food Waste Management through Innovative Animal Feeding Strategies

J. S. Hundal, Nilakshi Prakash Patil and Kalola Rajan Kumar
Department of Animal Nutrition
Guru Angad Dev Veterinary and Animals Sciences University, Ludhiana
Email: drjshundal@gmail.com

Introduction:

Every year, around 1.3 billion tons of food are wasted, causing emissions of greenhouse gases, groundwater depletion, land damage degradation and economic loss (FAO, 2021; Bigdeloo *et al*., 2021). In order to mitigate this problem and reduce its impact, a revolutionary bio waste management strategy is being implemented – optimising food processing waste through innovative animal feeding strategies. This innovative approach takes advantage of the existing practice of incorporating food scraps and other forms of trash into animal diets, particularly on farms (Nath *et. al.,* 2023). By utilizing food processing waste as animal feed, one can not only divert a significant portion of the waste from landfills but also create a sustainable and circular economy by transforming waste into valuable resources. This strategy not only addresses the issue of food waste disposal but also offers several other benefits. Firstly, by upcycling food processing waste as animal feed, we can significantly reduce the greenhouse gas emissions associated with food waste decomposition in landfills (Shurson, 2020). Additionally, feeding food waste to animals reduces the need for other feed sources, such as grains or soybeans, which can have negative environmental impacts themselves. Moreover, upcycling food processing waste through animal feeding can contribute to food security by utilizing resources that would otherwise go to waste. Furthermore, this strategy can potentially reduce the production costs for farmers by providing them with a cost-effective alternative to traditional animal feed. It is crucial to prioritize research and development in order to enhance food-waste-based animal feed, while simultaneously reducing production costs and waste disposal (Nath *et. al.,* 2023). This approach will result in improved conditions for both the animals and the environment.

Problem of Food Processing Waste:

The food processing industry generates a vast amount of waste due to various factors such as trimming, peeling, and discarding of parts that are not suitable for consumption. Additionally, the packaging materials and by-products from processing also contribute to the overall waste. Currently, there are several methods of waste disposal, including landfilling, incineration, and recycling (Nath *et al.* 2023). Landfilling is the most common method, where the waste is buried in designated areas. However, this method has limitations as landfills require large amounts of land, which is becoming scarce. Moreover, landfills can contaminate groundwater and release harmful gases into the atmosphere. Incineration, on the other hand, involves burning waste to generate energy but can release pollutants and greenhouse gases. Recycling is a more sustainable option, but it is often limited by the availability of recycling facilities and the difficulty of separating different types of waste. Therefore, finding more effective and environmentally friendly methods of waste disposal is crucial to mitigate the negative impacts of waste on the environment. Toxic chemicals and heavy metals leaking into the soil from improperly managed waste can eventually make their way into the food chain through plant absorption. This not only poses a risk to human health but also disrupts ecosystems and biodiversity. Additionally, the accumulation of waste in landfills produces methane, a potent greenhouse gas that contributes to climate change (Truong *et. al.,* 2019). Ultimately, addressing these negative environmental impacts requires a comprehensive approach that promotes waste reduction, proper waste segregation, and the adoption of sustainable waste management practices. Therefore, finding innovative solutions, like using this waste as animal feed, not only benefits the food industry but also addresses the critical issue of waste management and environmental sustainability.

Concept of Upcycling Food Waste and Environmental Benefits:

Upcycling refers to the process of transforming food processing waste into new and valuable products or materials (Nath *et. al.,* 2023). Unlike recycling, which involves breaking down materials to create new ones, upcycling aims to elevate the value of waste by repurposing it in a more creative and sustainable way. The practice of upcycling food processing waste into animal feed offers several benefits. Firstly, by upcycling food processing waste as animal feed, the amount of waste sent to landfills is greatly reduced. When organic waste decomposes in landfills, it releases methane, a potent greenhouse gas (Truong *et. al.,* 2019). By diverting this waste to animal feed, farmers can effectively manage and minimize greenhouse gas emissions. This not only helps to mitigate climate change but also reduces the environmental impact of waste disposal. Further, preservation of land and water resources is achieved by minimizing waste disposal through practices such as diverting organic waste to animal feed. Moreover, by minimizing the release of harmful chemicals from waste decomposition, water resources are protected from contamination, ensuring the preservation of clean and sustainable water sources for future generations. Secondly, by diverting this waste towards animal feed, it also reduces the need for other feed sources that may contribute to deforestation or intensive farming practices. Hence, using this waste as animal feed provides a cost-effective solution for farmers, as they can save on purchasing other feed sources (Zu Ermgassen *et. al.,* 2016). Lastly, upcycling promotes a more sustainable and circular approach to food production, where resources are utilized efficiently and waste is minimized, thus not only reduces environmental impact but also promotes economic growth and creates new opportunities for businesses and industries.

Animal Nutrition and Health:

Food processing waste can also have significant value in the realm of animal nutrition and health. Many byproducts from food production, such as fruit and vegetable waste, bakery wastes, agricultural wastes and leftover grains, can be repurposed as animal feed (Rivin *et. al.,* 2014; Wadhwa and Bakshi 2013; NRC 2001; Table 1). Several studies have been conducted to explore the positive impact of upcycled feed on livestock. Research has shown that animals fed with upcycled feed exhibit enhanced growth rates, improved digestion, and increased resistance to diseases (Wadhwa *et. al*, 2022, Singla *et al.,* 2021, Singh *et al.,* 2021). Moreover, these findings highlight the potential of upcycled feed to contribute to the development of a more sustainable and efficient agricultural system. Moreover, the milk byproducts, egg byproducts, meat byproducts, hatchery waste, etc. can be used to feed swine in many countries (Thaler, 2014). When dried bakery items up to 10% were fed to the broilers that had previously only been fed corn and soy, Truong *et al*. (2019) didn't find any considerable changes in weight gain or feed conversion ratios (FCR). Further, Siddiqui *et al*. (2021) didn't report the effect of feeding 30% dried bakery waste on weight gain, FCR, or feed intake in broilers. Some food waste contains small amounts of bioactive compounds that have the ability to provide health benefits (Martín Ortega *et. al.,* 2019)**.** For example, certain fruit and vegetable peels contain high levels of antioxidants that can improve immune function, health and performance of animals as well as lead to reduced use of antibiotics and other medications, further supporting sustainable farming practices (Wadhwa and Bakshi 2013). Singla *et al.* (2021) reported that *Emblica officinalis* fruit pomace (EFP) has a good source of total phenolics, saponins, flavonoids, and vitamin C. The feeding of EFP at 20 g/kg DM intake increases milk production and decreases methane production and intensity without impacting the health of buffaloes or the FA profiles of milk. Singh et al. (2021) found that *Aloe vera* waste (AVW) is rich in plant secondary metabolites, viz., tannins, saponins, and vitamin C, and the feeding of AVW at 20 g/kg DM intake would improve milk production performance, decrease the carbon footprint of milk production, and improve immunity without impacting the health of lactating cows. By utilizing food processing waste in animal feed, we can maximize the value of these resources and promote the health of both animals and the environment.

Table 1. Use of common different food or food processing waste in ruminant feed

S.No	Name of waste	Nutrition profile	Recommended level in animal feed
1	Surplus potato	CP 10.8%, Fat 0.5%, NDF 8.3%, Lignin 0.9%, TDN 81%, Starch 71.9%, ME 11.9 MJ/kg	10-12 kg/cow/d raw potatoes
2	Surplus carrots	CP 9.1%, Fat 1.0%, NDF 11.9%, Lignin 1.0%, Sugar 60%, ME 11.9 MJ/kg	Up to 15 kg/cow/d
3	Tomato pomace	CP 21.0%, Fat 11.9%, NDF 54.9%, Lignin 25.4%, ME 9.3 MJ/kg Good source of lycopene (an antioxidant and gives colour to meat)	10% in TMR or can replace barley plus cotton seeds up to 30% in concentrate
4	Empty pea pods	CP 19.8%, Fat 1.0%, NDF 60%, Sugar 35.8%	Can replace berseem hay up to 50% in TMR
5	Cauliflower waste	CP 19.9%, Fat 2.6%, NDF 33.7%	10-15 kg/cow/day and 20-30 kg/heifer/day
6	Sarson saag waste	CP: 14.5%, Soluble sugars: 6%	30-40 kg/cow/d

7	Baby corn husk:	CP 11.7, NDF 62%, Cellulose 24%	30-40 kg/cow/d
8	Citrus pulp	CP 8.0%, Fat 2.5%, NDF 21.6%, Lignin 2.50%, Starch 0.5%, Sugar 24.4%, ME 12.1 MJ/kg	Dried pulp can use 20% in TMR
9	Banana peels	CP 8%, NDF 35.8%, Cellulose 18%, Ripe contain up to 8%, Soluble sugars 13.8, Lignin 7-15% Total phenolics 4.8%	15-20 kg/cow/d
10	Dried distillers' grain with soluble (DDGS)	CP 27.8-48%, Fat4.5-9.3%, NDF 37.2-40.5%, Lignin 3.8-4.98%, ME 12.0-12.5 MJ/kg	20% of TMR or 4-5 kg/cow/day;
11	Sugar beet pulp	CP 8.9%, Fat 0.2%, NDF 49%, Lignin 1.8%, Starch 0.5%, Sugar 5.2%, ME 11.2 MJ/kg	Milking cow: 3.5 kg/d; Growing heifers: 5.5 kg/d
12	Maize gluten	CP 67.2%, Fat 1.23%, NDF 4.1%, Lignin 0.3%, Starch 17.6%, Sugar 10.5%, ME 16.6 MJ/kg Xanthophyll 300 ppm	Can replace 12.5% of SBM in TMR
13	Bakery meal	CP 10.8%, Fat 11.3%, NDF 3.0%, Starch 57.0%, Sugar 14.3, ME 14.5 MJ/kg	10% of TMR or 30% of concentrate on DM basis

CP: crude protein, NDF: neutral detergent fibre; TDN total digestible nutrients; ME metabolizable energy, TMR: total mixed ration; SBM: soybean meal.

Economic and Social Implications:

The utilization of upcycled feed in animal farming can have significant economic and social implications.

- By utilizing waste materials in animal feed, food processing companies can save on waste disposal expenses. By repurposing these materials, they can lower overall expenses and potentially reduce consumer prices. Additionally, this practice supports sustainable farming and lessens the environmental impact of food production.

- By utilizing waste materials in animal feed, farmers and animal feed manufacturers can create new opportunities for themselves. They can establish partnerships with food processing companies to acquire the waste materials, thereby reducing their own feed costs and increasing their profitability.
- Adopting sustainable waste management practices can improve an animal feed manufacturer's public perception and reputation. As consumers increasingly value environmental responsibility, businesses that prioritize sustainability are seen as ethical and trustworthy. This can attract new customers, strengthen brand loyalty, and provide financial benefits.

Challenges and Limitations:

Embracing sustainable waste management in animal feed presents challenges. Advanced technology and infrastructure are needed to upcycle food processing waste, requiring significant investment and research. Additionally, waste may contain pathogens that could harm animal health, necessitating rigorous safety and quality control. Transitioning to sustainable practices might disrupt operations and require employee retraining. Ensuring a steady supply of sustainable waste materials depends on cooperation across the supply chain.

Despite these challenges, the benefits—such as improved public perception and reputation—can outweigh the limitations. Solutions include collaborating with technology firms and research institutions to develop efficient processing methods, using biotechnology and fermentation to enhance feed value. Establishing guidelines with regulatory agencies and industry groups can help ensure standards are met. Educating consumers about the benefits of upcycled feed can boost demand and support a sustainable market. Effective implementation requires collaboration among food processors, farmers, and policymakers to share resources and address industry needs. This approach can facilitate widespread adoption of upcycled feed, contributing to a more sustainable and efficient food system.

In conclusion, optimizing food waste management through innovative animal feeding strategies presents a valuable opportunity to address the global issue of food waste. By diverting food processing waste to animal feed, we are able to utilize a valuable resource that would otherwise end up in landfills. Additionally, feeding animals with food waste helps to reduce the demand for traditional animal feed ingredients, such as grains and oil seed cakes, which can have a significant environmental impact. This practice not only benefits the environment but also creates a circular economy where waste is turned into a valuable resource for animal nutrition.

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Chapter-11

Nutritional Approaches for Designer Milk Fat Production in Dairy Animals

Shreekant Patil, M.M Pawar, R.B. Makwana, C.P. Modi and J.D. Chaudhary
Department of Animal Nutrition
College of Veterinary Science and Animal Husbandry
Kamdhenu University, Dantiwada
Email: drsrpatt@kamdhenuuni.edu.in

Introduction:

Milk is one of the healthiest foods and consumption of dairy products is linked with overall diet quality as it is rich in essential nutrients like minerals, vitamins and easily digestible proteins with balanced amino acid profile. Till date major emphasis has been given to increase the amount of milk but in today's scenario, more emphasis should be given to increase the quality of milk (Singh *et al.*, 2018). Now a day, a great attention is being given to manipulate the fatty acid (FA) profile of milk fat to respond to consumer concerns. On an average, percent fat composition of bovine milk is 4%, out of which 97-98% are triacyl glycerides. Milk fat contains 0.4% conjugated linoleic acid (CLA) with many different isomers including predominantly cis-9, trans-11 CLA (75-90% of total CLA) (Singh *et al.*, 2018). The bovine milk FA typically contains a high percentage of saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) comprising 69.4 and 25%, respectively. Further, 5% poly unsaturated fatty acids (PUFA) harmful trans FA represent approximately 4% of total milk FA (Stamey *et al*., 2012). Milk enriched with n-3 PUFA and oleic acid (C18: 1 cis-9) has been reported to decrease the incidences of cardio-vascular disease (Carrero *et al*., 2004). The lower level of saturated fatty acids (SFA) in milk is desired in conjunction with an increased amount of cis-mono unsaturated fatty acid (MUFA) and cis-poly unsaturated fatty acid (PUFA). Dietary manipulations in dairy animals have several opportunities in altering milk fatty acid profile and enhancing its nutraceutical properties which will be a boon to the health-conscious people.

Milk Fat Modification:

Modifications of milk fat are:

A. Decreasing saturated fatty acids (SFA) and increasing unsaturated fatty acids (USFA) level in milk

B. Increasing conjugated linoleic acid (CLA) level

C. Reducing cholesterol content

A) Decreasing SFA and Increasing USFA Level in Milk:

a) Pasture Grazing:

There are differences in the FA composition depending on the botanical composition of pasture that is within plant species, among grazing seasons and phenological stages of different plants. Pasture grazing increases the levels of alpha-linolenic acid (ALA), a beneficial omega-3 fatty acid. Pasture grazing leads to a higher proportion of unsaturated fatty acids in milk. Pasture grazing alters the fatty acid profile, increasing the levels of beneficial fatty acids and reducing the levels of less desirable ones. Pasture grazing promotes a healthier rumen environment, leading to more efficient fatty acid production. Pasture grazing tends to decrease the saturated fatty acid content in milk. Pasture grazing provides cows with higher levels of antioxidants and vitamins, which are transferred to the milk. Pasture grazing leads to a more favorable milk fat globule size, which can improve milk's nutritional and processing properties. Diets based on pasture and grass silage can improve the nutritional quality of milk by changing their FA composition toward less saturated FA and more polyunsaturated FA especially omega-3 FA (Suksombat and Chullanandana, 2008). Increasing proportion of fresh grass in the diet induced a linear decrease in milk fat content and a linear increase in USFA percentages at the expense of SFA (Couvreur *et al*., 2006).

b) Forage to Concentrate Ratio:

The increase in forage to concentrate ratio in feeding of animals have positive effect on increasing the concentration of desirable fatty acids. Forages contain more fibre than concentrates, which leads to a slower digestion rate and increased rumination. This promotes the growth of beneficial microbes that produce desirable fatty acids. Also, forages contain more polyunsaturated fatty acids (PUFAs) than concentrates. When PUFAs are fermented in the rumen, they are converted into rumenic acid (CLA), a desirable fatty acid with potential health benefits. Moreover, a higher forage to concentrate ratio leads to increased biohydrogenation, a process where unsaturated fatty acids are converted into saturated fatty acids. This results in a more favourable fatty acid profile. The total unsaturated fatty acids, total long chain fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids and total CLA (mg/g fat) values were linearly increased as roughage portion was gradually increased while total saturated fatty acids values were gradually decreased in crossbred dairy cows fed on higher roughage (Roughage to concentrate ratio - 50:50; 60:40; 70:30) to lower concentrate (Beyero *et al.,* 2015).

c) Supplementation of Oil Seeds or Vegetable Oils:

Oil seeds are natural sources of fat and protein in diets for lactating cows, and are usually fed as whole or crushed form. The oil of some seeds including soybean, rapeseed, cottonseed and sunflower seeds etc. were used. The addition of oilseeds and vegetable oils or their combination to diets of dairy cows can influence the composition of milk, especially the milk fat composition. Vegetable oils are rich in unsaturated fatty acids. Vegetable oils stimulate biohydrogenation, a process that converts unsaturated fatty acids into more desirable fatty acids. Vegetable oils, especially those high in linoleic acid, increase CLA production in the cow's rumen. Moreover, vegetable oils can modulate rumen fermentation, leading to a more efficient production of desirable fatty acids. In a study (Dai *et al*., 2011) on lactating cows supplemented with 2% rapeseed oil, 2% peanut oil and 2% sunflower seed oil led to significantly higher PUFA and UFA while SFA values were significantly decreased in treatment groups as compared to control group. Similarly, dietary addition of 15 mL of castor oil and 2 g of ricin oleic acid from castor oil in lactating Kankrej cow daily led to increase in USFA, MUFA and PUFA in milk while SFA values were decreased as compared to control group (Joshi *et al*., 2020; Pawar *et al.,* 2021). Furthermore, unsaturated fatty acids and monounsaturated fatty values were significantly increased while saturated fatty acids values were significantly decreased in milk of Kankrej cows and Mehsana buffaloes supplemented with 125 ml and 250 ml of Sunflower oil daily (Ahuja *et al*., 2023; Patel *et al*., 2023).

d) Combination of Fish Oil and Vegetable Oil:

Marine oils derived from fish oil or algae are a rich source of omega-3 like eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) fatty acids. DHA is an omega-3 FA essential for the structural development of the brain and eyes in the infants and maintenance of normal vision and neural functions in adults. Combinations of fish oil with vegetable oils were tested as supplement in the diet of dairy animals by several workers and their results showed that increased the proportion of beneficial fatty acids. Fatahnia *et al.* (2008) carried out trial to determine the effect of feeding fish oil, soybean oil, or their combination on milk composition of Holstein cows. Experimental diets consisted of: 1) Control diet; 2) A diet with 3% (DM basis) added fat from menhaden fish oil; 3) A diet with 3% added fat from soybean oil; and 4) A diet with 1.5% added fat from fish oil and 1.5% fat from soybean oil. They observed that EPA, DHA and total n-3 FA were significantly increased in fish oil and fish oil plus sunflower oil supplemented groups as compared to control and only sunflower oil supplemented group.

e) Supplementation of Bypass Fat/Rumen Protected Fat or Inert Fat:

Supplementation of bypass fat in dairy cows can improve milk fatty acid composition in several ways. Bypass fats provide a concentrated source of energy, reducing the cow's reliance on de novo fatty acid synthesis. Bypass fats can alter the fatty acid profile of milk, increasing the levels of desirable fatty acids. Bypass fats reduce the need for de novo fatty acid synthesis, resulting in less saturated fatty acids in milk. Bypass fats can increase the levels of unsaturated fatty acids in milk, improving its nutritional value. Bypass fats can lead to a more favorable milk fat globule size, improving milk's processing properties. Some bypass fats, like linoleic acid, can increase CLA production in milk. Bypass fats can decrease the saturated fatty acid content in milk, making it more desirable for human consumption. Some bypass fats, like algal oil, can increase the levels of omega-3 fatty acids in milk. Thus, bypass fats can enhance the nutritional value of milk, making it more appealing to consumers.

Dietary fat, that resists lipolysis and biohydrogenation by rumen microorganisms, but gets digested in lower digestive tract, is known as bypass fat or rumen protected fat or inert fat. Prevention of biohydrogenation of PUFA in the rumen subsequently increasing the supply of PUFA to the mammary gland. Such milk will be beneficial to the patients who have heart problems. Supplementation of bypass fats in the diet of lactating cows generally decreases the proportions of short and medium chain saturated fatty acids of milk fat due to reduction in de novo FA synthesis in mammary gland. The oleic acid and linoleic acid in milk fat were significantly increased in bypass fat fed dairy cows as compared to the control (Purushothaman *et al*., 2008). Similarly, Shah *et al*., (2004) evaluated the utilization of different sources of unsaturated long-chain fatty acids in diets that is soybean oil (SO) and calcium salts of long chain unsaturated fatty acids (CS) for dairy cows during early lactation on the milk fatty acid profile. They reported that there was a decrease in concentration of medium chain fatty acids C12-C16and an increase in concentrations of long-chain fatty acids in milk fat for the animals fed the diets CS and SO when compared with diet control.

B) Dietary Manipulations to Increase Conjugated Linoleic Acid (CLA) Level in Milk:

CLA is the positional and geometric isomer of linoleic acid. Linoleic and linolenic acid are the main subtract for CLA synthesis in ruminant. Primary dietary source of CLA for humans are food product derived from ruminant animal mostly cow, including meat fat, milk, cheese, yogurt and butter. Conjugated linoleic acids (CLA) have a range of potent health effects, including suppression of carcinogenesis, ant obese effect, modulation of the immune system, reduction in atherosclerosis, diabetes and decreased body fat mass in humans. Following strategies can help improving CLA content of milk fat.

a) Pasture Grazing and CLA:

Pasture grazing increases the production of vaccenic acid, a precursor to CLA. Pasture grazing stimulates the production of CLA, a desirable fatty acid with potential health benefits. Diets based on pasture and grass silage can improve the nutritional quality of milk by changing their FA composition toward less saturated FA and more polyunsaturated FA (Dhiman *et al*., 1999). The CLA concentration in the milk fat was highest for cows on 100% pasture, intermediate for cows on 2/3 pasture, and least for cows receiving 1/3 pasture (Dhiman *et al*., 1999). Grazing or feeding of diversified grasses resulted in the production of milk fat richer in alpha lipoicacid (ALA) and CLA (Mishra *et al*., 2004). An increase in CLA content was reported in milk fat obtained from cows grazing in alpine pasture as compared to cows fed silage and concentrates that is barn fed. The increased content and proportion of CLA in milk fat from high altitudes probably due to the high content of PUFA in some fodder species such as *Leontodon hispidus*, Birds foot trefoil and *Lotus corniculatus* (Kraft *et al*., 2003).

b) Feeding of Vegetable Oils:

Feeding vegetable oils (sunflower seed oil, soybean oil, etc.) to cows can improve Conjugated Linoleic Acid (CLA) content in milk. Vegetable oils are rich in linoleic acid, a precursor to CLA. Linoleic acid from vegetable oils undergoes biohydrogenation in the rumen, producing CLA. Vegetable oils modify rumen fermentation, favoring CLA production. Studies have reported that there is 10-20% increase in CLA content in milk with sunflower seed oil supplementation. He *et al*., (2004) reported that CLA cis-9, trans-11 concentration in milk from cows fed diets containing sunflower seeds (SS) @ 7% was increased to 7.89 mg g–1 fatty acid as compared to non-supplemented cows of control group (3.88 mg g–1 fatty acids). Suksombat and Chullanandana (2008) studied the effects of soybean oil supplementation (150 g/day) on accumulation of conjugated linoleic acid in dairy cows. They observed that Cis-9, trans-11 CLA, Trans-10, cis-12 CLA, Trans -9, trans-11 CLA and Total CLA in milk were significantly increased in group supplemented with soybean oil as compared to control group.

c) Inclusion of Flaxseed in Diets:

Among vegetable fat sources, linseed has a very high contents of n-3 linoleic FA (around 30% of total FA) and low amounts of SFA. Similar to vegetable oils, feeding of flax seeds to cows improves Conjugated Linoleic Acid (CLA) content in milk. Flax seeds are rich in linoleic acid, a precursor to CLA. Linoleic acid from Flax seeds undergoes biohydrogenation in the rumen, producing CLA. Flax seeds modify rumen fermentation, favoring CLA production. Studies have reported that there is 20-30% increase in CLA content in milk with Flax seeds supplementation. Glasser *et al*. (2008) studied the effect of dietary inclusion of flaxseed on milk composition of dairy cows. The flaxseed inclusion @ 4-5% of dry matter (DM) resulted in significantly higher proportion of conjugated linoleic acid isomers (CLA) in flaxseed included group.

C) Dietary Manipulations to Decrease Cholesterol Content in Milk:

In spite milk has exceptional nutritional value, there is resistance to consumption of dairy products because milk lipid is high in cholesterol. Feeding cows diets high in unsaturated fatty acids, such as those found in soybean or canola oil can reduce cholesterol levels. Plant sterols or stanols, such as those found in soybeans or pine trees, can reduce cholesterol levels. High-fiber diets can reduce cholesterol levels by binding to bile acids and removing them from the body. Certain additives, such as beta-glucans or psyllium, can help reduce cholesterol levels. Limit or avoid feeding saturated fatty acids, such as those found in palm oil or coconut oil. Omega-3 fatty acids, particularly EPA and DHA, have been shown to reduce cholesterol levels. Certain rumen modifiers, such as ionophores, can alter rumen fermentation and reduce cholesterol levels. Vitamin E and antioxidants can help reduce oxidative stress and cholesterol levels. Consumption of saponins, which occur in leguminous plants, such as fenugreek, has been shown to decrease circulating cholesterol concentrations in many species, including humans (Shingfield *et al*., 2008).

Conclusion:

Milk fat is more responsive to dietary alterations than protein and can be changed over 3% percent unit. We can modify the milk fat composition by, a) Decreasing saturated fatty acids (SFA) and increasing unsaturated fatty acids (USFA) level in milk, b) Increasing conjugated linoleic acid (CLA) level, c) Reducing cholesterol content. Milk fat, due to its relatively high proportion of saturated fatty acids has been associated with human cardiovascular health problems. Therefore, dietary manipulations in dairy animals have several opportunities in improving milk production, modifications of milk composition, fatty acid profile and enhancing nutraceutical properties of milk

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Technologies Adopted for Feeding of High Yielding Dairy Animals

Chander Shakhar Sharma
Prabhat Consultancy Services, Jaipur
Email: shekhar00000@rediffmail.com

In Indian Scenario, we consider high yielding animals with following Lactation Yields

- Buffalo- 3600 liters + milk
- Indigenous Cattle- 3000 liters + milk
- Cross BreedCattle-6000 liters + milk

Various Technologies across the world are used for feeding of high yielding dairy animals. In India, commercial farms have started using some of these technologies to meet demands of high yielding dairy animals reared at their farms.

Computerized Feed Delivery Systems:

These systems can be automated to feed cows based on their energy needs, which can vary depending on their lactation phase. Some systems can adjust for factors like milk production and lactation stage.

Internet of Things (IoT):

IoT devices can help monitor feeding and drinking methods, which can lead to better nutrition and increased milk production.

Sensors and Sensing Devices:

Electronic sensors can be used to monitor cows for various things, including when they are in heat.

Apart from above 3 technologies, following technologies are used in isolation or to support above 3 main technologies

1. Automatic programmable feeders
2. Mixing and feeding robots
3. Artificial intelligence
4. Data processing, and Machine learning methods

These technologies are used in 2 main types of feeding systems for high yielding dairy cattle.

1. Component feeding-for small herds
2. Total mixed ration (TMR)-for large herds

Now let us see what benefits these technologies offer.

Computerized Feed Delivery Systems:

a. Precision-Computerized systems can accurately deliver feed at the right time and in the right amount
b. Efficiency-Computerized systems can save time and labor, and can be more efficient for larger farms.
c. Reduced waste-Computerized systems can help reduce feed waste by delivering feed directly to individual pens.
d. Improved animal welfare-Computerized systems can help improve the welfare of the animals by providing a correct diet and reducing contamination.
e. Reduced pollution-Computerized systems can help reduce pollution by preventing feed from degrading in the water or depositing at the bottom of the tank.
f. Improved safety-Computerized systems can help improve biosafety by restricting daily access to tanks.
g. Easier supervision-Computerized systems can alert the farmer if abnormalities are noticed, so that timely intervention is possible if necessary.

Internet of Things (IoT):

a. Predict herd reproduction
b. Milk production
c. Animal diseases

These above are based on a combination of external and internal factors, statistical data, economic indicators, staff information, and laboratory data. This not only reduces costs associated with maintaining cow health, labor, and reproduction but also helps achieve strategic business goals, such as expanding production and opening new units.

Sensors & Sensing Devices:

a. Sensors and sensing devices can be used in dairy feeding to improve animal health, reduce costs, and enhance sustainability.
b. Improved feed intake monitoring-Sensors can track how much dairy cows eat, which can help reduce milk production costs and improve animal health.
c. Early detection of disease-Sensors can monitor animal health and detect disease outbreaks before they become large-scale, which help farmers take action to prevent losses.

d. Improved animal welfare-Sensors can track animal behavior, such as feeding, rumination, and activity & it enables farmers to understand what factors influence animal welfare.
e. Improved milk quality-Sensors can help farmers determine when to milk their cattle, which can help maintain milk quality.
f. Reduced labor costs-Sensors can help farmers care for more animals with fewer people, which can reduce production costs.
g. Improved sustainability-Sensors can help farmers optimize feed management, which can improve sustainability.

Automatic Programmable Feeders:

a. Improved Nutrition-Feeders can provide the right amount and type of feed to each cow at the right time. This can help cows reach their optimal production cycle phase and meet their nutritional needs.
b. Calf health-Automated feeders can help calves develop faster, gain more weight, and reach first insemination earlier. They can also help calves avoid nutritional scours by ensuring the correct osmolality of their feed.
c. Disease detection-Feeders can monitor feeding and drinking habits, and report any deviations to help detect illness early.
d. Reduced labor-Automated feeders can reduce the amount of manual labor required on a dairy farm.
e. Reduced feed waste-Automated feeders can reduce feed shrink, which can lead to a reduction in feed refusal.
f. Calf weaning-Automated feeders can help with gradual weaning, which can help calves avoid post-weaning growth slumps.
g. Calf feeding behavior-Automated feeders can provide reports on how much each calf is eating and how often they visit the feeder & helps identify calves that might be getting sick.

Mixing & Feeding Robots:

a. Advanced feeding systems such as mixing and feeding robots have been developed to deliver the entire ration to cow groups multiple times a day with accuracy and consistency.
b. Feed mixing and delivery is highly accurate and minimizes labor requirements.

c. The MFR is designed to deliver smaller amounts of feed more often throughout the day and night.
d. The robotic delivery system ensures that an extremely even row of feed is delivered along the feed lane at each feeding.
e. In addition to keeping feed fresher throughout the day, feeding smaller amounts per "meal" helps prevent overconsumption by the cow and helps maintain a proper rumen pH and digestive function.

Artificial Intelligence:

a. Nutrition, one of the fundamental aspects of dairy farming, significantly impacts milk production and cow health.
b. AI-powered data analytics helps in preparing personalized and balanced diets for individual cows.
c. The system considers aspects like the age, breed, weight, milk yield, and overall health status of cows.
d. By modifying the feeding plans based on real-time data, AI ensures that each cow gets the exact amount of nutrients needed, leading to optimized milk production and overall cow health.
e. This approach minimizes feed wastage, promoting sustainable farming practices.

Data Processing & Machine Learning Methods:

a. By analyzing data on individual cow milk components, ML algorithms can provide insights into the best feeding and management practices for each cow, resulting in higher milk yields, improved welfare, and better overall herd performance.
b. The use of technologies, including ML, has the potential to revolutionize the dairy industry by providing farmers with real-time, accurate data on the milk components of individual cows, enabling them to make informed decisions and maximize their profitability while ensuring the welfare and health of their animals.

Now let us see the basic aspects of component feeding system used in small herds.

1. Small dairy farms may have their herds tied up in tie-stall barns and feed the cows individual ingredients (forage, grain, supplement).
2. This is referred to as component feeding while laborious it provides for individualized feeding.
3. Individual feeding: Each cow has a defined feeding space.

4. No special equipment: There is no need for specialized mixing or feed delivery equipment.
5. Easy diet adjustments: The amount of concentrate fed to each cow can be adjusted.
6. Mimics TMR: Component feeding mimics a total mixed ration (TMR) by avoiding large swings in rumen pH.
7. This can help prevent issues like acidosis and milk fat depression.

Total Mixed Ration (TMR) is a method of feeding used in large herds. Basic aspects of TMT are

1. Total Mixed Ration (TMR) can be described as a mixture of both the roughage and the processed ingredients, formulated and mixed to supply the cow's requirements, in a form that precludes selection.
2. It is designed to be the sole feed source given over a 24-hour period and fed ad lib. for optimum results.
3. This cannot be accomplished without the use of accurate weighing equipment and adequate and proper mixing equipment (feed mixer wagon).

Let us see the benefits of using TMR system of feeding

1. Increased dry matter intakes (DMI). Peak DMI is achieved 4 to 8 weeks earlier than conventional systems.
2. Increased milk production by approximately 5 to 8%, Each additional kg DM consumed increases milk yield by 0.9 to 1.5 Liters.
3. Improved fat tests because of improved rumen fermentation, and optimal pH (acidity) levels of 6.2 to 6.8 achieved in the rumen, resulting in both maximal rumen fermentation and cellulose digestion leading to the formation of acetic acid, the precursor of butterfat production.
4. Reduced digestive upsets due to each bite of feed having the same composition, minimizing pH fluctuations in the rumen.
5. Optimal protein synthesis in the rumen, as microbial protein synthesis is maximized at a rumen pH of 6.3 to 7.4.
6. No need to feed mineral/vitamin supplements as all the requirements can be included in the TMR.
7. Eliminate concentrate feeding at milking.

8. A wider variety of less palatable feeds can be utilized in the ration as these are masked by the other ingredients by the elimination of selection.
9. Better control of the cow's diet.

Some key points should be considered for success of good TMR program for feeding high Yielding dairy animals.

1. Forage quality must be good.
2. Accurate weighing.
3. Accurate moisture determination of feeds.
4. Correctly balanced ration.
5. Dry cow programme, i.e. adequate preparation.
6. Feed intake monitoring is absolutely critical.

For implementing successful TMR program, following is the checklist.

1. To maximize Dry matter intake (DMI), feed the ration in 4 to 5 portions over the day, avoiding rations with over 50% moisture.
2. Ensure that the ration contains a minimum of 27% NDF (amount of cell wall in plant tissue) or 19% ADF-cellulose and lignin (DM basis), with 75% of the ration NDF derived from forage/roughage.
3. Non-structural carbohydrates (NSC-sugars, starches, and fructans) should range from 38 to 40% of the dry matter (DM) for optimal rumen fermentation.
4. Higher NSC levels can lead to lactic acid fermentation and acidosis, thereby reducing Dry matter intake (DMI).
5. The ration should contain an optimal rumen degradable protein (RDP) to undegradable (UDP), or bypass, protein ratio of 60 to 40 to ensure adequate rumen fermentation, as well as adequate bypass protein for high production.
6. Excess rumen degradable protein (RDP) will be detrimental to Dry matter intake (DMI).
7. Include a maximum of half a kg of unprotected fat and half a kg of protected fat in the ration as excessive fat levels decrease palatability.
8. The inclusion of feed buffers and a yeast culture is recommended to ensure optimal rumen fermentation.

Animal Nutrition and Health: A Vital Link for Global Health

Jagriti Srivastav and Deepika Dhuria
Department of Animal Nutrition
College of Veterinary and Animal Science, Bikaner
Rajasthan University of Veterinary and Animal Sciences, Bikaner (Raj.)
Email: drjagriti.srivastav@gmail.com

Animal nutrition and health significantly impact global health by directly influencing the nutritional quality of animal products consumed by humans, affecting the risk of zoonotic diseases, and impacting environmental sustainability through animal waste management, thus affecting overall human health and food security. Animal nutrition and health are core elements for sustainable development and livestock production. By improving animal health livestock production can be maximized and optimal health for the human being can be achieved. Global health management requires the full cooperation of the animal, human, plant, and environmental health sectors. The aim is to develop global strategies to tackle major diseases or broader health threats, such as antimicrobial resistance, promote the One Health approach, and recognize animal, human, and environmental health interdependence. One Health concept is defined by the One Health Commission (2010) as the collaborative effort of multiple disciplines to obtain optimal health for people, animals, and our environment. The One Health approach explains that human, animal, and plant health are interdependent and bound to the health of the ecosystems in which they exist. Animal nutrition and health influence global health in the following ways:

Nutritional Value of Animal Products: Proper animal nutrition ensures the production of high-quality animal products rich in essential nutrients like protein, vitamins, and minerals, which are crucial for human health, especially in regions where dietary diversity is limited.

Zoonotic Disease Transmission: Poor animal health can lead to the spread of zoonotic diseases, which can be transmitted from animals to humans, like salmonella, avian influenza, and rabies, posing a significant public health threat.

Antimicrobial Resistance: Overuse of antibiotics in livestock can contribute to the development of antibiotic-resistant bacteria, impacting the effectiveness of antibiotics used to treat human infections.

Environmental Impact: Animal agriculture practices, including feed production and waste management, can significantly affect the environment through greenhouse gas emissions, water pollution, and deforestation, ultimately impacting human health.

Food Security: Healthy livestock populations are essential for ensuring a stable food supply, especially in developing countries where many people rely on animal products as a primary source of protein.

Impact of Animal Nutrition and Health in Global Health: Animal nutrition has a pronounced direct impact not only on animal health but also indirectly through animal products on human health and through excreta on the environment. Zoonotic diseases of animal origin are very well known to affect human health, public health, and the economy. The global demand for livestock products is increasing continuously, likely increasing the risk of emerging infectious diseases and the consumption of antimicrobials in livestock production systems. The quality of animal feed affects the composition of the intestinal microorganisms, playing an essential role in digestive health and, consequently, overall health. A balanced diet in animals favors microbial diversity in the digestive system of humans contributing to various health benefits, improved immune systems, and efficient digestion. Additionally, it also helps to improve the sustainability of the intestinal microbiome.

Foods of animal origin are extremely rich sources of essential vital nutrients. Meat is particularly rich in essential amino acids, vitamin B_{12}, folate, and other B vitamins, iron, zinc, selenium, vitamin A, and vitamin D. Ruminant milk and meat also contains conjugated linoleic acid (CLA), which is attributed to anti-carcinogenic and other effects. CLA is produced in the rumen by microbial modification of fats from feed and in the udder from microbial-modified oleic acid. Egg is considered the only dietary source of n-3 and n-6 long-chain polyunsaturated fatty acids. By applying proper animal nutrition practices these animal products can be enriched with more nutrients. The proportion of harmful saturated fatty acids can be reduced and the proportion of desirable polyunsaturated fatty acids and conjugated linoleic acid (CLA) can be increased. The content of CLA is affected by the diet, especially by polyunsaturated fatty acid content and the conditions in the rumen. Fortification of animal products with certain vitamins and minerals as well as some natural plant bioactive substances is also a beneficial approach.

A wide range of bioactive compounds are naturally found in animal products that can positively impact human health in different ways. Bioactive substances including carotenoids, polyunsaturated fatty acids, and peptides, have been investigated to exhibit health advantages such as anti-inflammatory, immune regulating, and anticancer properties and are proven to play an important role in preventing and managing illnesses such as cancer, heart diseases, and neurodegenerative conditions. Phytochemicals are natural compounds obtained from plants that function as antioxidants, antimicrobials, and anti-inflammatory and anticancer agents. These ingredients have elements such as phytosterols which lower cholesterol levels in animals and support heart health. Another ingredient tocopherols, acts as an antioxidant that shields cells from harm caused by oxidation while the polyphenols exhibit properties that may help combat inflammation and prevent cancer development.

The bioactive compounds present in milk and milk byproducts, including polyunsaturated fatty acids, caseins and albumins proteins, flavonoids, catechins, hydroxycinnamic acids, immunoglobulins like IgG, IgM, IgE, IgD, cytokines including interleukins, interferon, phenols, peptides, and terpenes, and essential oils significantly impact the quality of animal products. The proportion of linoleic and linolenic acids tends to be improved in the milk obtained by animals kept on grazing along with concentrate supplementation in comparison to stall-fed animals. The linoleic and linolenic acids improve the sensory qualities and shelf life of milk. Dairy products also contain sulfur-containing amino acids, whey proteins such as β lactoglobulin, and essential vitamins and minerals. Additionally, bioactive peptides released during fermentation or cheese aging process contribute to the antioxidant activity of dairy products. Consuming dairy products with antioxidants helps to reduce the chances of lifestyle diseases.

Carnosine is the natural bioactive compound present in meat which showed antioxidant properties and is potentially beneficial in healthy and diseased myocardial models. Chicken slaughterhouse by-products create protein hydrolysates which lowers blood pressure and improves endothelial dysfunction. These hydrolysates act as an antioxidant, anti-inflammatory, anti-coagulant, anti-anemic, cardioprotective, hepatoprotective, and neuroprotective agent. Eggs are considered a functional food as they contain high-quality protein, balanced amino acid content, and low calories. Eggs also contain cholesterol, vitamins (A, B, D, E, and K), minerals (calcium, iron, and phosphorus), and carotenoids such as lutein and zeaxanthin. Eggs are a rich source of polyunsaturated fatty acids, especially n-3 fatty acids. These n-3 fatty acids prevent the risk of cardiovascular, degenerative disease, cancer, and inflammatory conditions in humans. Due to this fact, research is being conducted to promote the consumption of these n-3 fatty acids employing functional animal products. Animal products can be positively modified through strategic nutrition practices to achieve value-added animal products. Bioactive compounds in animal diets, either from grazing environments or using pre-formulated diets, have shown promise in boosting the bioactive properties of these products and potentially impacting chronic disease in both animals and humans. For example, the egg can be enriched by the inclusion of conventional or unconventional ingredients in the hen diet to boost compounds such as n-3 fatty acids. However, it is important to consider that increasing the content of fatty acids can make them more susceptible to oxidation, so it is desirable to fortify bird diets with antioxidants such as vitamin E, selenium, and carotenoids. The use of certain carotenoids as additives in poultry feed is aimed at improving the color of egg yolks. Additionally, they help neutralize singlet oxygen and free radicals and protect against oxidative damage. Sardine oil, langostilla (red shrimp) flour, conjugated linoleic acid, tuna oil, shrimp meal, squid flour, and selenium have been used for this purpose.

The ingredients such as probiotics, prebiotics, organic acids, antioxidants, and antibiotics are known to exhibit positive impacts on both animal and human health. Probiotics are the live microorganisms that improve the balance of beneficial bacteria in the gut e.g. Lactobacillus, Bifidobacterium, Bacillus, and Enterococcus. The benefits of probiotics in animals include improved growth, feed utilization, and intestinal health. Prebiotics are the foods that feed the good bacteria in the gut. These are typically high-fiber foods like beta-glucans and inulin. Prebiotics offer benefits including improved immune responses, intestinal health, and overall performance of the animals. Organic acids, such as formic acid and propionic acid, are used as preservatives in animal feed. Antioxidants impact the oxidative and microbial stability of animal products which is very important for the health of consumers as oxidized substances are harmful to health.

Ruminants are considered the main contributor to the emission of greenhouse gases because large amounts of carbon dioxide and methane are produced during the fermentation process in the rumen. The rumen fermentation can be modified in a manner that animals may produce less methane by using certain plants that contain bioactive compounds like condensed tannins and saponins. This could reduce greenhouse gas emissions and improve the efficiency of feed utilization in animals. The use of minerals in cheated form can be regarded as environmentally friendly, as their requirements are lower due to better digestibility and availability leading to less negative interactions in the absorption.

Conclusion: Animal nutrition and health are closely related to global human health thus improving animal nutrition and health practices with the help of advanced nutritional strategies can positively affect the livestock as well as human health. Additionally, these emerging practices also contribute to improved environmental sustainability ultimately supporting one health concept.

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Animal Health and Nutrition: Evolving Trends and Future Outlook

R.K. Dhuria, Deepika Dhuria, Jagriti Srivastav, Shahji Phand and Sushrirekha Das

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EDITORS

R.K. Dhuria
RAJUVAS

Deepika Dhuria
RAJUVAS

Jagriti Srivastav
RAJUVAS

Shahji Phand
MANAGE

Sushrirekha Das
MANAGE

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Collaboration: Rajasthan University of Veterinary and Animal Sciences, Bikaner.