Role of Nutrition, Supplements and Feed Additives in Animals Exposed to Heat Stress

Muhammad Usman Saleem[1*], Abdul Asim Farooq[2], Muhammad Arshad Javid[1,3], Muhammad Abdul Basit[1], Sheraz Ahmed Bhatti[4], Saeed Murtaza[2], Maqbool Hussain Shah[2], Muhammad Asif[5], Muhammad Nawaz[6] and Faisal Ayub Kiani[2]

[1]Department of Biosciences, Faculty of Veterinary Sciences, Bahauddin Zakariya University, Multan, Pakistan.
[2]Department of Clinical Sciences, Faculty of Veterinary Sciences, Bahauddin Zakariya University, Multan, Pakistan.
[3]Department of Anatomy and Histology, Faculty of Animal Husbandry & Veterinary Science, Sindh Agriculture University, Tandojam, Pakistan.
[4]Department of Pathobiology, Faculty of Veterinary Sciences, Bahauddin Zakariya University, Multan, Pakistan.
[5]Institute of Continuing Education and Extension, University of Veterinary & Animal Sciences, Lahore, Pakistan.
[6]Department of Environmental Sciences, Bahauddin Zakariya University, Multan, Pakistan.
*Corresponding author: usmansaleem@bzu.edu.pk

Abstract

Nutrition shows a key role in health and production of livestock and poultry. All the necessary nutrients including lipids, carbohydrates, proteins, vitamins and minerals form a balanced diet which is essential for the best performance and productivity. Addition of feed additives and supplements are the essential strategies in animal and poultry nutrition to combat the nutritional deficits and adverse impact of heat stress. In animal and poultry production, heat stress is significant challenge which causes animals to consume less feed leading to decrease production. Feed additives and supplements improve vital nutrient absorption and support the immune system by strengthening gut health and mitigating the adverse effects of heat stress. The feed supplements like amino acids, energy, proteins, vitamins and minerals that have been revealed to increase animal performance and production. The feed additives such as prebiotics, probiotics, and enzymes boost intestinal health and support immunological response. The health, welfare, and productivity of poultry and livestock are connected with the balanced nutrition. Feed additives and supplements are vital for improving the animal production and reducing the adverse effects of heat stress for providing vital nutrients and boosting intestinal health.

Keywords: Animal health, Feed efficacy, Farmer sustainability, Gut health, Balanced Diet

Cite this Article as: Saleem MU, Farooq AA, Javid MA, Basit MA, Bhatti SA, Murtaza S, Shah MH, Asif M, Nawaz M and Kiani FA, 2025. Role of nutrition, supplements and feed additives in animals exposed to heat stress. In: Şahin T, Ameer K, Abid M and Tahir S (eds), Nutritional Foundations of Holistic Health: From Supplements to Feed Strategies. Unique Scientific Publishers, Faisalabad, Pakistan, pp: 298-305. https://doi.org/10.47278/book.HH/2025.487

A Publication of Unique Scientific Publishers

Chapter No: 25-42

Received: 02-Feb-2025
Revised: 16-Apr-2025
Accepted: 23-May-2025

Introduction

Nutrition in animal feed refers to the study and practice of providing animals with a balanced diet to promote their productivity, growth, health, and reproduction. It entails suppling vital nutrients such as water, proteins, fats, carbohydrates, vitamins, and minerals in appropriate proportions (Wu, 2017). Depending on the species' age, physiological state, and intended use (milk, meat, or eggs), animal feed is designed to satisfy their unique nutritional needs (Celi et al., 2017). Proper nutrition reduces the environmental impact of livestock production through optimal nutrient consumption and improves feed efficiency, immunological response, and overall performance (Terry et al., 2020).

Two essential elements of animal nutrition are concentrate and roughage. Roughages are low-energy, high-fiber feeds such silage, hay, grasses, and crop waste. By encouraging healthy rumen function, they are vital for ruminants such as cows, sheep, and goats, helping with digestion and gut health (Tomar et al., 2022). Whereas, concentrates are high-energy, low-fiber diets that include oilseeds (soybean meal), cereals (corn, barley, and oats), and byproducts like molasses. They offer dense nutrients, especially protein and energy, to support development, reproduction, and the production of meat or milk (Hills et al., 2015). For the best possible health and productivity, animals must be fed a balanced diet that includes both concentrates and roughages.

Animal health is largely dependent on proper nutrition, which affects immunity, productivity, growth, and reproduction (Wu, 2022). The essential components of animal nutrition include **c**arbohydrates which are the main energy source in animal diets made from grains, forages and silages. Energy is essential for maintenance, reproduction and milk production. Proteins provide the amino acids required for tissue growth and repair as well as for the synthesis of hormones, enzymes, and antibodies. Oils and fats are concentrated energy sources and necessary for the absorption of fat-soluble vitamins that are A, D, E, and K. Additionally, fats improve palatability and supply vital fatty acids that are necessary for immunological and reproductive health. Numerous physiological processes are regulated by vitamins. Vitamin D encourages the growth of bones, while vitamin A helps immunity and vision. Vitamin B-complex supports neurological and metabolic function, while vitamin E serves as an antioxidant (Saha & Pathak, 2021). Calcium, phosphorus, magnesium, and potassium are essential minerals that are necessary for healthy

bones, neuron function, and enzyme activation. Growth and reproduction are enhanced by trace minerals like as copper, zinc, and selenium (Yadav et al., 2024). Animals must be well hydrated for optimal health and productivity, as water is required for many biological functions, including digestion, nutrition delivery, and temperature regulation (Giri et al., 2020). The fiber that is mostly present in roughages helps ruminants' digestive system. It helps the rumen ferment properly and guards against conditions like acidosis (Goulart et al., 2020).

Animal nutrition is essential for maintaining and improving health. It affects immunity, productivity, growth, and reproduction, making it essential to the effective management of livestock and poultry (Alagawany et al., 2021). A healthy diet guarantees that animals get the vital nutrients required for their physiological processes, enhancing their overall health and performance.

Key Roles of Nutrition in Animal Health

A healthy diet supplies the enough energy, vitamins, proteins and minerals for growth, tissue formation and development (Saha & Pathak, 2021). Balanced diets are especially important for young animals to attain the best possible weight increase and skeletal progress. An animal's immune system is strengthened by proper nutrition, allowing it to fend against diseases and infections. Minerals like zinc, selenium, and vitamin E increase immunity by encouraging the formation of antibodies, which are essential for animal health (Munteanu & Schwartz, 2022).

Impact of nutrition on reproduction and fertility is substantial. Diets high in energy help regulate hormones, and vital minerals like calcium and phosphorus are important for development of reproductive organs. Metabolic problems, impaired immunity, and decreased susceptibility to infections can result from nutrient deficits or imbalances (Yang et al., 2021). According to reports, dairy animals who do not get enough calcium may develop milk fever (Nurye & Animut, 2022).

Healthy diet ensures the digestive system runs smoothly. Balanced rations prevent problems like colic or acidosis, while high-fiber diets encourage healthy rumen activity in ruminants (Goulart et al., 2020). Nutrition directly impacts meat quality, milk production and egg yield. Trace minerals improve the carcass quality and feed conversion efficiency, whereas energy and protein are essential for nursing animals. Nutrition that is species-specific and balanced improves general health, reduces the chance of illness, and maximizes productivity (Sawant et al., 2024).

Importance of balanced diet

In context of animal and poultry nutrition, a balanced diet is a feed formulation that serves the animal's physiological and production demands by including all necessary elements, like carbohydrates, proteins, fats, vitamins, minerals, fiber, and water in appropriate quantities. It prevents nutritional excesses or deficits and ensures optimal health, growth, reproduction, and productivity (Saha & Pathak, 2021).

The balanced diets improve growth rates, minimize feed waste, and optimize nutrient utilization. Milk, meat, and egg production are all directly enhanced by proper nutrition (Choi et al., 2023). Sufficient amounts of minerals, protein, and energy promote fertility and lessen reproductive problems. It ensures a strong immune system to fend off illnesses by preventing nutritional deficits and abnormalities (Munteanu & Schwartz, 2022). The foundation of animal and poultry health is a balanced diet. Adapting the diets to species, age, and production objectives ensures profitable and sustainable farming methods (Alagawany et al., 2021).

New Trends in Animal and Poultry Nutrition

The goal of developments in animal and poultry nutrition is to solve economic and environmental issues while improving sustainability, productivity, and health. The precision feeding and substitute feed ingredients are the main focuses of recent trends (Bist et al., 2024).

Adapting diets to each animal's unique nutritional requirements based on age, weight, stage of production, and health is the main goal of modern farming (Kumar et al., 2023). Increased prices for conventional protein sources like soybean meal have prompted research into substitutes like insect-based proteins, algae, and single-cell proteins. This strategy minimizes feed waste, increases nutrient efficiency, and lowers costs. These sustainable options give high-quality nutrition while decreasing environmental impacts (Gil et al., 2024).

Total Mixed Ration (TMR) is a technique for feeding animals, particularly ruminants, in which all feed ingredients like roughages, concentrates, minerals, and vitamins are combined into a consistent blend. This reduces wastage and selective feeding while ensures that every meal offers a balanced diet improving nutrient intake and productivity (Bueno et al., 2020).

Feed additives that improve digestion, nutritional absorption, and immunological response include probiotics (good bacteria), prebiotics (non-digestible carbohydrates that support gut health), and enzymes (phytase). They also enhance gut health and lessen the need for antibiotics (Al-Jaf & Del, 2019). Essential oils and plant extracts are phytogenic compounds that are becoming more and well-known due to their antimicrobial, anti-inflammatory, and growth-promoting qualities (Ivanova et al., 2024).

Reducing the carbon footprint of feedstuffs by using substitute materials like as climate-smart cereals, food industry waste, and agricultural byproducts is part of the movement toward sustainable farming (Uddin & Kebreab, 2020). The genetic basis of nutrition utilization is being studied to create personalized diets that increase productivity and resistance to disease. Balanced diet, nutritional demand estimation and animal health monitoring are supported by some techniques like feed optimization software, accuracy sensors and artificial intelligence. These trends confirm the future sustainability in animal farming which also lead to healthier animals, less environmental influence, and better economic competence (Akintan et al., 2024).

Difference between Supplements and Feed Additives

Supplements and feed additives are vital constituents of animal nutrition that progress output, production, and well-being. In spite of their ostensible resemblances, they have numerous functions and are employed in different ways (Pandey et al., 2019).

i. **Feed Supplements**

Concentrated nutritional foundations known as feed supplements are given to animals to make up for nutritional shortages. When the

principal diet is lacking in some nutrients, they are critical. The animal feed often comprises feed supplements containing proteins, minerals, and vitamins (Arthington & Ranches, 2021). The feed supplements, which mainly address nutritional inadequacies for ideal health and production, are normally provided in ration in calculated amounts to balance the diet (Kumar et al., 2023).

ii. **Feed Additives**

Non-nutritional components called feed additives are provided to animal feed to boost digestion, health, production performance, feed efficacy, disease anticipation, and product excellence. These are enzymes, prebiotics, antibiotics and probiotics which are used in minute quantities for curative determinations (Pandey et al., 2019).

iii. Basic Differences

1. Additives are used in fixed quantities, while supplements are added in higher quantities (Ukwo et al., 2022).
2. Supplements provide essential elements, while additives improve feed performance without contributing considerably to nutritional levels (Hassen et al., 2022).
3. Supplements address dietary shortages, while additives enhance feed efficiency, animal well-being, and production (Hassen et al., 2022).

Both are essential for managing livestock and poultry effectively, guaranteeing their best health and financial output.

Supplements and their Importance in Animal Nutrition

The supplements are concentrated sources of vital nutrients that are fed to animals to make up for inadequacies in their main diet. For best possible growth, reproduction, and general health, they guarantee that animals get enough proteins, vitamins, minerals, and other essential nutrients (Arthington & Ranches, 2021). When the available feed, such as forages and grains, does not supply all the nutrients needed for particular physiological or production needs, supplements become especially crucial. Supplements are essential for maintaining the best possible health, productivity, and financial sustainability in poultry and livestock management (Alagawany et al., 2021).

1. Supplements ensure that animals acquire a balanced quantity of nutrients (Leroy et al., 2022).
2. Sufficient supplementing improves meat quality, egg and milk production (Choi et al., 2023).
3. Minerals and vitamins promote fertilization, hormonal equilibrium, and offspring health (Van Emon et al., 2020).
4. Vitamin E, zinc, and selenium supplements boost immunity and lower the risk of disease.
5. Calcium and phosphorus supplements help prevent milk fever and skeletal issues (Sawant et al., 2024).
6. Protein and energy supplements promote quick weight gain and healthy growth (Wu & Li, 2022).

Feed Additives and their Importance in Animal Nutrition

Feed additives are non-nutritional materials or chemicals that are added to animal feed to enhance the animals' overall performance, quality, and well-being (Lambo et al., 2021). The purpose of these additives is to maximize animal health, productivity, and feed utilization while lowering the risk of disease and enhancing the sustainability of livestock and poultry operations. They are not intended to directly supply vital nutrients like proteins, vitamins, or minerals (Pandey et al., 2019).

1. Probiotics and enzymes enhance nutrient use, improving feed conversion ratios and lowering feed expenses.
2. Additives can boost milk and egg production, and weight gain (Jha et al., 2020).
3. Additives keep the gut bacteria in equilibrium, avoiding digestive problems including bloating and diarrhea (Pandey et al., 2019).
4. Antioxidants, probiotics, and trace minerals boost immunity and help animals fend against illnesses (Jha et al., 2020).
5. Additives can lessen the effects of dangerous toxins in the feed, prevent infections, and stop disease outbreaks (Dawood et al., 2018).
6. Additives increase feed acceptance, mainly in animals that are less hungry or young animals making the switch to solid diet (Kalam et al., 2023).
7. Probiotics and enzymes can lower waste products like methane and nitrogen excretion, promoting more environmentally friendly agricultural methods (Jha et al., 2020).

Heat Stress and its Negative Effects on Animal Health

Heat stress (HS) is caused by exposure to high temperatures and humidity levels that are greater than an animal's ability to control body temperature. It interrupts physiological and metabolic procedures; this condition has a serious negative impact on animal welfare, health, and output (Das et al., 2016).

Animals under heat stress consume less food to lessen internal heat generation, which consequences in inferior development rates and lower energy intake. As a result of changed metabolism and lessened nutritional accessibility for milk production, dairy animals have lower milk yields and quality (West, 2003). Disrupted estrous cycles in female animals, lower sperm quality in male animals and decreased conception rates are reproductive issues caused by heat stress (Boni, 2019).

Because prolonged HS deteriorates the immune system, animals are more prone to illnesses and infections. The respiratory system is stressed when animals with HS pant to release heat. Dehydration and metabolic difficulties result from the loss of water and electrolytes caused by unnecessary perspiration or panting (Rashamol et al., 2020). In extended HS circumstances, conditions like acidosis, heat exhaustion, and heat stroke are predominant. Decreased mobility, symptoms of impatience, and excessive craving for water or shade may be exhibited by stressed animals (Cheshire, 2016).

Role of Feed Supplements and Additives to alleviate Heat Stress in Animals

To alleviate the detrimental impact of heat stress in animals, feed supplements and additives are essential tools. Both animal health and farm economics are enhanced by using appropriate supplementation and additives which play vital role in improving the resilience of poultry and livestock in hot environments (Conte et al., 2018).

i. **Role of Feed Supplements**

The HS causes electrolyte loss through perspiration and panting, which results in dehydration and abnormalities in bodily processes. Potassium, chloride and salt containing supplements boost the hydration level, electrolyte balance, nerve and muscle functions (Dharmarajan, 2021). Reproductive health, immune system response and general metabolism all depend on vitamins as well as minerals. To prevent deficits caused by the depletion of these vital nutrients during heat stress, animal's immune system is strengthened and reproductive effectiveness is maintained by feed supplements (Samara et al., 2025).

Under heat stressed conditions, animals frequently consume less feed, which lowers output. Supplements high in energy, like fats and oils, offer a readily accessible energy source to boost metabolic processes, and sustain productivity. In animals, HS raises oxidative stress, which can harm cells and compromise immune system performance. The free radicals are neutralized by antioxidants like vitamin E and selenium, which protect cells and increase an animal's ability to withstand stress (Digiacomo et al., 2022).

ii. **Role of Feed Additives**

In addition to lowering feed intake, the HS can damage intestinal health. The probiotics and prebiotics improve feed conversion rates, preserve digestive health under stressful situations, support gut function, and encourage a healthy microbiome and nutrient absorption (Jha et al., 2020). In spite of lower feed intake, some feed additives, such as growth stimulants and amino acids, promote muscle growth and milk production, hence reducing the detrimental effects of HS on growth and productivity (Sakkas, 2023). Mycotoxin contamination of feed may increase as a result of HS. Feed containing mycotoxin binders reduces detrimental effects of toxic substances on animal health by preventing their absorption (Çelik, 2020).

Supplements used in Animal feed

Common types of supplements used in animal feed are categorized by the nutrients they provide

i. Protein supplements
ii. Mineral supplements
iii. Vitamin supplements
iv. Energy supplements
v. Non-protein nitrogen (NPN) supplements (for ruminants)

i. Protein Supplements

The protein supplements provide essential amino acids and nitrogen to support growth, repair and maintenance of body tissues. The common sources include soybean meal, fish meal and alfalfa meal. They enhance protein synthesis by providing the necessary building blocks for muscle, enzyme and hormone production (Wu et al., 2014).

The protein supplements support tissue regeneration, muscle fiber development and immune cell production. They improve growth rates, milk production and reproductive health. Adequate protein intake also strengthens the immune system, enhances enzyme activity and supports proper metabolic functions contributing to overall animal health (Celi et al., 2017).

ii. Mineral Supplements

The mineral supplements provide essential elements like calcium, phosphorus, zinc and selenium are critical for various physiological functions in animals. The common sources include dicalcium phosphate, limestone and trace mineral premixes. Minerals support enzyme functions, bone health, immune system function and metabolic processes (Saha et al., 2021).

Calcium and phosphorus promote the bone development while zinc supports skin and tissue repair. Selenium aids in cellular protection. Adequate mineral intake improves bone strength, reproductive health, immune function and growth. Minerals like zinc and selenium also enhance antioxidant defenses, helping animals withstand stress and infections thus improving overall health and productivity (Zheng et al., 2022).

iii. Vitamin Supplements

The vitamin supplements provide essential vitamins like A, D, E, and B-complex crucial for maintaining animal health. The common sources include synthetic vitamins or plant-based sources. Vitamins act as cofactors in the metabolic reactions, supporting immune function, vision, growth and energy production (Alpert, 2017). Vitamin A supports epithelial cell integrity and skin health whereas vitamin D promotes bone mineralization (Bikle & Christakos, 2020). Moreover, vitamin E functions as an antioxidant protecting cells from oxidative damage. They prevent deficiencies leading to conditions like impaired vision, rickets and poor immunity respectively (Reed, 2023).

iv. Energy Supplements

The energy supplements provide concentrated sources of carbohydrates, fats and oils, such as molasses, vegetable oils and grains to support animal energy needs. Energy supplements provide readily available energy for metabolic processes supporting growth, reproduction and lactation. Energy supports tissue growth and repair by providing fuel for cellular activities including muscle development and fat deposition (Kim & Wakshlag, 2023). They improve feed conversion rates, prevent weight loss and enhance milk or egg production. Adequate energy intake supports optimal growth, reproductive function and overall health, especially in high-production animals under stress or increased energy demands (Wasti et al., 2020).

v. Non Protein Nitrogen Supplements

Non-protein nitrogen (NPN) supplements such as urea and ammonium salts provide nitrogen for ruminants to synthesize microbial

proteins in the rumen. The NPN supplements are converted by rumen microbes into ammonia which is used to form amino acids and proteins benefiting the requirement of animal protein (Zurak et al., 2023).

The NPN supports the growth of rumen microbes, enhancing microbial protein production and improving gut health. The NPN supplementation boosts protein availability in ruminants improving growth, milk production and overall feed conversion efficiency. It reduces the reliance on high-protein feed sources, supporting cost-effective and sustainable feeding strategies (Hassen et al., 2022).

Feed Additives used in Animal feed

Common feed additives used in animal and poultry feed include:

i. Probiotics
ii. Prebiotics
iii. Enzymes
iv. Antioxidants
v. Antibiotics
vi. Mycotoxin Binders

i. Probiotics

Probiotics are live microorganisms typically beneficial bacteria like *Lactobacillus* and *Bifidobacterium* that are added to animal feed to enhance gut health. Probiotics promote a healthy balance of gut microbiota by inhibiting harmful bacteria competing for nutrients and producing beneficial metabolites like lactic acid (Ashaolu, 2020).

They support the integrity of the intestinal lining, improve villus height and enhance mucosal immunity protecting against pathogens. Probiotics improve digestion, nutrient absorption and immune function. They reduce gastrointestinal issues enhance feed conversion and support overall health leading to better growth, reproduction and disease resistance in animals (Jha et al., 2020).

ii. Prebiotics

Prebiotics are non-digestible fibers or compounds such as fructooligosaccharides (FOS) and inulin, that promote the growth of beneficial gut bacteria in animals. Prebiotics selectively stimulate the growth and activity of beneficial microorganisms like *Lactobacillus* and *Bifidobacterium* by providing fermentable substrates (You et al., 2022).

Prebiotics improve gut health by enhancing the intestinal mucosal barrier, increasing villus height and promoting beneficial microbiota which enhances overall gut function. Prebiotics support digestion, enhance nutrient absorption and boost the immune system by fostering a healthy gut microbiota. They help prevent gastrointestinal disorders, improve feed efficiency and enhance animal performance (Ashaolu, 2020).

iii. Enzymes

Enzymes in animal feed such as phytase, amylase and cellulase are added to enhance digestion and nutrient absorption. Enzymes break down complex feed components into more absorbable forms improving nutrient utilization. The enzyme supplementation improves the structure of the intestinal lining by promoting efficient digestion and nutrient absorption enhancing villus health and gut function (Bedford & Apajalahti, 2022). Enzymes increase feed conversion efficiency, reduce nutrient waste and enhance growth rates particularly in non-ruminants. They improve gut health, support metabolic functions and help reduce the environmental impact of feed digestion (Liang et al., 2022).

iv. Antioxidants

Antioxidants such as vitamin E, selenium and beta-carotene are added to animal feed to combat oxidative stress. Antioxidants neutralize free radicals and reactive oxygen species (ROS), preventing cellular damage caused by oxidative stress and inflammation. Antioxidants protect cell membranes, reduce oxidative damage to tissues and support the health of organs particularly liver and muscles (Sawant et al., 2024). They enhance immune function, reduce inflammation, support reproductive health and improve tissue repair. Antioxidants help protect against chronic diseases, enhance growth and improve overall health particularly under stress or intensive production conditions (Jha et al., 2020).

v. Antibiotics

Antibiotics are used in animal feed to prevent and treat bacterial infections, promote growth and improve feed efficiency. Common antibiotics include penicillin, tetracyclines and bacitracin. Antibiotics target and inhibit bacterial growth by interfering with cell wall synthesis, protein synthesis or DNA replication selectively killing or inhibiting harmful bacteria (Baran et al., 2023).

Antibiotics reduce inflammation and tissue damage caused by bacterial infections supporting tissue healing and reducing lesions. They improve feed conversion, growth rates and overall health by preventing bacterial infections. However, the overuse of antibiotics can contribute to resistance and disrupt gut microbiota balance (Low et al., 2021).

vi. Mycotoxin binders

Mycotoxin binders are substances added to animal feed to neutralize or bind harmful mycotoxins such as aflatoxins and ochratoxins preventing their absorption. Mycotoxin binders like bentonite clay or yeast cell walls physically bind to mycotoxins in the gastrointestinal tract reducing their bioavailability and preventing absorption into the bloodstream (Kihal et al., 2022). They help in minimizing damage to tissues particularly in liver and kidneys by reducing toxin-induced inflammation and cellular damage. Mycotoxin binders improve feed intake, growth and immune function reducing the negative impacts of mycotoxin contamination and supporting overall animal health and productivity (Lai et al., 2022).

Conclusion

Feed additives and supplements are essential for reducing the negative effects of heat stress (HS) on livestock and poultry, which in turn increases milk, meat, and egg production while providing local farmers with substantial economic and food security benefits. Electrolytes, vitamins, minerals like zinc, and energy-dense feeds help maintain hydration, immune function, and metabolic efficiency, which guarantees consistent milk yield, meat quality, and egg production. The negative effects of reduced feed intake due to HS are countered by feed additives such as probiotics and enzymes, which improve gut health and nutrient absorption. By preserving optimal production levels during HS, these interventions benefit farmers by boosting productivity, which raises livestock farming income. Supporting animal health feed additives and supplements help farmers fulfill rising food needs and improve regional food security. Consistent livestock production helps ensure a steady supply of animal-based protein, which is essential for local people.

References

Akintan, O., Gebremedhin, K. G., & Uyeh, D. D. (2024). Animal Feed Formulation-Connecting Technologies to Build a Resilient and Sustainable System. *Animals*, *14*(10), 1497.

Alagawany, M., Elnesr, S. S., Farag, M. R., Tiwari, R., Yatoo, M. I., Karthik, K., Michalak, I., & Dhama, K. (2021). Nutritional significance of amino acids, vitamins and minerals as nutraceuticals in poultry production and health–a comprehensive review. *Veterinary Quarterly*, *41*(1), 1-29.

Al-Jaf, K. A. H., & Del, Y. K. (2019). Effect of different feed additives on growth performance and production in livestock. *International Journal of Agriculture and Forestry*, *9*(1), 16-31.

Alpert, P. T. (2017). The role of vitamins and minerals on the immune system. *Home Health Care Management & Practice*, *29*(3), 199-202.

Anee, I. J., Alam, S., Begum, R. A., Shahjahan, R. M., & Khandaker, A. M. (2021). The role of probiotics on animal health and nutrition. *The Journal of Basic and Applied Zoology*, *82*, 1-16. https://doi.org/10.1186/s41936- 021-00250-x

Arthington, J. D., & Ranches, J. (2021). Trace mineral nutrition of grazing beef cattle. *Animals*, *11*(10), 2767.

Ashaolu, T. J. (2020). Immune boosting functional foods and their mechanisms: A critical evaluation of probiotics and prebiotics. *Biomedicine & Pharmacotherapy*, *130*, 110625. https://doi.org/10.1016/j.biopha.2020.110625

Baran, A., Kwiatkowska, A., & Potocki, L. (2023). Antibiotics and bacterial resistance—a short story of an endless arms race. *International Journal of Molecular Sciences*, *24*(6), 5777.

Bedford, M. R., & Apajalahti, J. H. (2022). The role of feed enzymes in maintaining poultry intestinal health. *Journal of the Science of Food and Agriculture*, *102*(5), 1759-1770.

Bikle, D., & Christakos, S. (2020). New aspects of vitamin D metabolism and action—Addressing the skin as source and target. *Nature Reviews Endocrinology*, *16*(4), 234-252.

Bist, R. B., Bist, K., Poudel, S., Subedi, D., Yang, X., Paneru, B., Mani, S., Wang, D., & Chai, L. (2024). Sustainable poultry farming practices: A critical review of current strategies and future prospects. *Poultry Science*, 103(12), 104295.

Boni, R. (2019). Heat stress, a serious threat to reproductive function in animals and humans. *Molecular Reproduction and Development*, *86*(10), 1307-1323.

Bueno, A. V. I., Lazzari, G., Jobim, C. C., & Daniel, J. L. P. (2020). Ensiling total mixed ration for ruminants: a review. *Agronomy*, *10*(6), 879.

Celi, P., Cowieson, A. J., Fru-Nji, F., Steinert, R. E., Kluenter, A. M., & Verlhac, V. (2017). Gastrointestinal functionality in animal nutrition and health: new opportunities for sustainable animal production. *Animal Feed Science and Technology*, *234*, 88-100. https://doi.org/10.1017/S0022029920001090

Çelik, K. (2020). The efficacy of mycotoxin-detoxifying and biotransforming agents in animal nutrition. In *Nanomycotoxicology* (pp. 271-284). Academic Press.

Cheshire Jr, W. P. (2016). Thermoregulatory disorders and illness related to heat and cold stress. *Autonomic Neuroscience*, *196*, 91-104. DOI: 10.1055/s-0040-1713847

Choi, J., Kong, B., Bowker, B. C., Zhuang, H., & Kim, W. K. (2023). Nutritional strategies to improve meat quality and composition in the challenging conditions of broiler production: a review. *Animals*, *13*(8), 1386.

Conte, G., Ciampolini, R., Cassandro, M., Lasagna, E., Calamari, L., Bernabucci, U., & Abeni, F. (2018). Feeding and nutrition management of heat-stressed dairy ruminants. *Italian Journal of Animal Science*, *17*(3), 604-620.

Das, R., Sailo, L., Verma, N., Bharti, P., Saikia, J., & Kumar, R. (2016). Impact of heat stress on health and performance of dairy animals: A review. *Veterinary world*, *9*(3), 260.

Dawood, M. A., Koshio, S., & Esteban, M. Á. (2018). Beneficial roles of feed additives as immunostimulants in aquaculture: a review. *Reviews in Aquaculture*, *10*(4), 950-974.

Dharmarajan, K. (2021). Water, potassium, sodium, and chloride in nutrition. *Geriatric gastroenterology*, (pp.539-554), Springer.

DiGiacomo, K., Chauhan, S. S., Dunshea, F. R., & Leury, B. J. (2022). Strategies to Ameliorate Heat Stress Impacts in Sheep. In *Climate Change and Livestock Production: Recent Advances and Future Perspectives* (pp. 161-174). Singapore: Springer Singapore.

Gil, M., Rudy, M., Duma-Kocan, P., Stanisławczyk, R., Krajewska, A., Dziki, D., & Hassoon, W. H. (2024). Sustainability of Alternatives to Animal Protein Sources, a Comprehensive Review. *Sustainability*, *16*(17), 7701.

Giri, A., Bharti, V. K., Kalia, S., Arora, A., Balaje, S. S., & Chaurasia, O. P. (2020). A review on water quality and dairy cattle health: a special emphasis on high-altitude region. *Applied Water Science*, *10*(3), 1-16.

Goulart, R. S., Vieira, R. A., Daniel, J. L., Amaral, R. C., Santos, V. P., Toledo Filho, S. G., Cabezas-Garcia, E. H., Tedeschi, L. O., & Nussio, L. G. (2020). Effects of source and concentration of neutral detergent fiber from roughage in beef cattle diets on feed intake, ingestive behavior, and ruminal kinetics. *Journal of Animal Science*, *98*(5), skaa107.

Hassen, A., Ahmed, R., Alam, M. S., Chavula, P., Mohammed, S. S., & Dawid, A. (2022). The effect of feed supplementation on cow milk productivity and quality: a brief study. *International Journal of Agriculture and Veterinary Sci*ences, *4*(1), 13-25.

Hills, J. L., Wales, W. J., Dunshea, F. R., Garcia, S. C., & Roche, J. R. (2015). Invited review: An evaluation of the likely effects of individualized feeding of concentrate supplements to pasture-based dairy cows. *Journal of Dairy Science*, *98*(3), 1363-1401.

Ivanova, S., Sukhikh, S., Popov, A., Shishko, O., Nikonov, I., Kapitonova, E., Krol, O., Larina, V., Noskova, S., & Babich, O. (2024). Medicinal plants: a source of phytobiotics for the feed additives. *Journal of Agriculture and Food Research*, 16, 101172. https://doi.org/10.1016/j.jafr.2024.101172

Jha, R., Das, R., Oak, S., & Mishra, P. (2020). Probiotics (direct-fed microbials) in poultry nutrition and their effects on nutrient utilization, growth and laying performance, and gut health: A systematic review. *Animals*, *10*(10), 1863.

Kalam, S. M., Savsani, H. H., Chavda, M. R., Odedra, M. D., Naliyapara, H. P., Patel, S. D., & Belim, S. Y. (2023). Flavoured additives in ruminant nutrition: A review. *Indian Journal of Animal Nutrition*, *40*(1), 1-8.

Kim, H. T., & Wakshlag, J. J. (2023). Nutrition and theriogenology: a glimpse into nutrition and nutritional supplementation during gestation, lactation, weaning and breeding dogs and cats. *Veterinary Clinics: Small Animal Practice*, *53*(5), 1083-1098.

Kihal, A., Rodríguez-Prado, M., & Calsamiglia, S. (2022). The efficacy of mycotoxin binders to control mycotoxins in feeds and the potential risk of interactions with nutrient: a review. *Journal of Animal Science*, *100*(11), skac328.

Kumar, P., Abubakar, A. A., Verma, A. K., Umaraw, P., Adewale Ahmed, M., Mehta, N., Hayat, M. N., Kaka, U., & Sazili, A. Q. (2023). New insights in improving sustainability in meat production: opportunities and challenges. *Critical Reviews in Food Science and Nutrition*, *63*(33), 11830-11858.

Lai, Y., Sun, M., He, Y., Lei, J., Han, Y., Wu, Y., Bai, D., Guo, Y., & Zhang, B. (2022). Mycotoxins binder supplementation alleviates aflatoxin B1 toxic effects on the immune response and intestinal barrier function in broilers. *Poultry Science*, *101*(3), 101683.

Lambo, M. T., Chang, X., & Liu, D. (2021). The recent trend in the use of multistrain probiotics in livestock production: An overview. *Animals*, *11*(10), 2805.

Leroy, F., Abraini, F., Beal, T., Dominguez-Salas, P., Gregorini, P., Manzano, P., Rowntree J., & Van Vliet, S. (2022). Animal board invited review: Animal source foods in healthy, sustainable, and ethical diets–An argument against drastic limitation of livestock in the food system. *Animal*, *16*(3), 100457.

Liang, Q., Yuan, M., Xu, L., Lio, E., Zhang, F., Mou, H., & Secundo, F. (2022). Application of enzymes as a feed additive in aquaculture. *Marine Life Science & Technology*, *4*(2), 208-221.

Low, C. X., Tan, L. T. H., Ab Mutalib, N. S., Pusparajah, P., Goh, B. H., Chan, K. G., Letchumanan, V., & Lee, L. H. (2021). Unveiling the impact of antibiotics and alternative methods for animal husbandry: A review. *Antibiotics*, *10*(5), 578.

Munteanu, C., & Schwartz, B. (2022). The relationship between nutrition and the immune system. *Frontiers in nutrition*, *9*, 1082500. https://doi.org/10.3389/fnut.2022.1082500

Nurye, M., & Animut, G. (2022). Calcium Requirement about Milk Fever of Dairy Animals. *Global Journal of Animal Scientific Research*, 10(2), 60-80.

Pandey, A. K., Kumar, P., & Saxena, M. J. (2019). Feed additives in animal health. *Nutraceuticals in veterinary medicine*, (pp.345-362). Springer.

Rashamol, V. P., Sejian, V., Bagath, M., Krishnan, G., Archana, P. R., & Bhatta, R. (2020). Physiological adaptability of livestock to heat stress: an updated review. *Journal of Animal Behaviour and Biometeorology*, *6*(3), 62-71.

Reed, D. J. (2023). Interaction of vitamin E, ascorbic acid, and glutathione in protection against oxidative damage. In *Vitamin E in health and disease* (pp. 269-282). CRC Press.

Saha, S. K., & Pathak, N. N. (2021). *Fundamentals of animal nutrition* (pp. 219-246). Singapore, Springer.

Saha, S. K., Pathak, N. N., Saha, S. K., & Pathak, N. N. (2021). Mineral nutrition. *Fundamentals of animal nutrition*, (pp.113-131). Springer.

Sakkas, P. (2023). The Effects of Feed Additives on Farm Animals under Heat Stress Conditions. In *Sustainable Use of Feed Additives in Livestock: Novel Ways for Animal Production* (pp. 285-326). Springer International Publishing.

Samara, E. M., Al-Badwi, M. A., Abdoun, K. A., Abdelrahman, M. M., Okab, A. B., Bahadi, M. A., & Al-Haidary, A. A. (2025). The interrelationship between macrominerals and heat stress in ruminants: current perspectives and future directions-a review. *Veterinary Research Communications*, *49*(1), 29.

Sawant, K., Redkar, V., & Alate, M. (2024). Optimizing Animal Health and Performance through Nutritional Strategies: Insights for Veterinary Practice. *Revista Electronica de Veterinaria*, *25*(1), 477-488.

Terry, S. A., Basarab, J. A., Guan, L. L., & McAllister, T. A. (2020). Strategies to improve the efficiency of beef cattle production. *Canadian Journal of Animal Science*, *101*(1), 1-19.

Tomar, K., Tiwari, S., Singh, D., & Kumar, D. (2022). Feeding Management of Ruminant Livestock. *Smart Agricultural Technologies,* 71-84. https://www.researchgate.net/publication/363847193

Uddin, M. E., & Kebreab, E. (2020). Impact of food and climate change on pastoral industries. *Frontiers in Sustainable Food Systems*, *4*, 543403. https://doi.org/10.3389/fsufs.2020.543403

Ukwo, S. P., Udo, I. I., & Ndaeyo, N. (2022). Food additives: overview of related safety concerns. *Food Science and Nutrition Research*, *5*(1), 1-10.

Van Emon, M., Sanford, C., & McCoski, S. (2020). Impacts of bovine trace mineral supplementation on maternal and offspring production and health. *Animals*, *10*(12), 2404.

Wasti, S., Sah, N., & Mishra, B. (2020). Impact of heat stress on poultry health and performances, and potential mitigation strategies. *Animals*, *10*(8), 1266.

West, J. W. (2003). Effects of heat-stress on production in dairy cattle. *Journal of Dairy Science*, *86*(6), 2131-2144.

Wu, G. (2022). Nutrition and metabolism: Foundations for animal growth, development, reproduction, and health. *Recent advances in animal nutrition and metabolism*, (pp.1-24). Springer.

Wu, G. (2017). *Principles of animal nutrition*. CRC Press, Boca Raton. https://doi.org/10.1201/9781315120065

Wu, G., Bazer, F. W., Dai, Z., Li, D., Wang, J., & Wu, Z. (2014). Amino acid nutrition in animals: protein synthesis and beyond. *Annual Reiew of Animal Bioscience*, *2*(1), 387-417.

Wu, G., & Li, P. (2022). The "ideal protein" concept is not ideal in animal nutrition. *Experimental Biology and Medicine*, *247*(13), 1191-1201.

Yadav, S., Yadav, J., Kumar, S., & Singh, P. (2024). Metabolism of Macro-elements (Calcium, Magnesium, Sodium, Potassium, Chloride and Phosphorus) and Associated Disorders. In *Clinical Applications of Biomolecules in Disease Diagnosis: A Comprehensive Guide to Biochemistry and Metabolism* (pp. 177-203). Singapore: Springer Nature Singapore.

Yang, F., Yang, Y., Zeng, L., Chen, Y., & Zeng, G. (2021). Nutrition metabolism and infections. *Infectious Microbes & Diseases*, *3*(3), 134-141.

You, S., Ma, Y., Yan, B., Pei, W., Wu, Q., Ding, C., & Huang, C. (2022). The promotion mechanism of prebiotics for probiotics: A review. *Frontiers in Nutrition*, *9*, 1000517. https://doi.org/10.3389/fnut.2022.1000517

Zheng, Y., Xie, T., Li, S., Wang, W., Wang, Y., Cao, Z., & Yang, H. (2022). Effects of selenium as a dietary source on performance, inflammation, cell damage, and reproduction of livestock induced by heat stress: A review. *Frontiers in Immunology*, *12*, 820853. https://doi.org/10.3389/fimmu.2021.820853

Zurak, D., Kljak, K., & Aladrović, J. (2023). Metabolism and utilisation of non-protein nitrogen compounds in ruminants: a review. *Journal of Central European Agriculture*, *24*(1), 1-14.