American Journal of Biology and Natural Sciences
https://biojournals.us/index.php/AJBNS
ISSN: 2997-7185

Emerging Technologies in Animal Nutrition and Their Impacts on Sustainability and Productivity: Article Review

Sara Hatem Abdullah
Department of Industrial plants, College of Medicinal and Industrial plants, Kirkuk University, Kirkuk, Iraq

Received: 2025, 15, Jun
Accepted: 2025, 21, Jul
Published: 2025, 20, Aug

Abstract: This review summarizes the recent progression of new approaches in animal nutrition technology and its application on productivity, welfare, and environmental sustainability. The recent advancements like phytogenic feed additives, probiotics, and prebiotics (i.e., oligosaccharides and galactomannans particularly isolated from guar meal) or multidietary enzymes with complex polysaccharide hydrolysis abilities of NSPs combined with α-glucanase activities towards enhanced utilization potential for the above-said glycoconjugates in monogastric animals, as well as nanobiotechnology tools, are promising ways to achieve precision feeding having better nutrient bioavailability such that there exists overall least dependency upon antibiotic-fed animal health but not at the expense of spoilage to the environment by reducing excreta-emanated deteriorating footprint like GHGs generation, etc. These technologies enable individualized nutrition management, resulting in improved resource efficiency and sustainability. The

review also addresses economic and social implications, opportunities, and barriers to adoption. Barriers to adoption are described, and the possibility of future work line recurrence is presented: need for long-term safety studies at different life stages; generalization across environments, breeds, and melding with advanced predictive analytics. Overall, new animal nutrition technologies can contribute significantly to sustainable livestock production worldwide.

Keywords: Animal nutrition, feed additives, probiotics, nanotechnology, livestock productivity.

Introduction

The role of animal nutrition in improving livestock productivity and sustainability is very important. Optimal feeding strategies practiced for animals directly affect animals' growth rate, milk yield, and reproductive efficiency as well as the overall livestock herd health. Thus, they are crucial factors in the sustainability of the profit in livestock-related enterprises that eventually enhance profitability to the furthest extent (Palani et al., 2024).

Nevertheless, the modern domesticated animal industry has encountered overwhelming obstacles such as deficient natural sources, increasing cost of feedstuffs, environmental pollution, and people have started to emphasize measures that will help in the decrease of greenhouse gases (Steinfeld et al., 2006; Palani et al.,2022; Gerber et al.,2013). All these problems are made acute by world population growth and the increasing demand for animal protein, making it imperative to establish sustainable systems of productive feeding.

Recent advances in emerging technologies offer the potential to effectively confront these challenges. Phytogenic feed additives, precision feeding technologies, probiotics and prebiotics supplements, as well as enzymatic supplements and feed-based nanotechnologies, have demonstrated promising perspectives in terms of enhancing FE, animal performance, and overall environmental matters (Makkar et al., 2014; Nasir & Grashorn, 2010; Tedeschi & Fox, 2020). The incorporation of such emerging nutritional technologies that improve efficiency in nutrient utilization could maximize the proportion of nutrients retained to provide livestock feed, minimize feeding costs for these animals, and reduce their impact on land use (e.g., deforestation) or other environmental issues related to greenhouse gas emissions, such as methane and nitrous oxide (Place & Mitloehner, 2014; Tedeschi & Fox, 2020).

The need to accept such novel feeding systems is increasingly topical as the cost of production escalates and there are restrictions on conventional feed availability. For instance, precision feeding technologies permit that diets are formulated and delivered according to the precise requirements of animals, resulting in savings of resources and less environmental pollution (Tedeschi & Fox, 2020; Pomar & Remus, 2019). Furthermore, the

use of phytogenic feed additives and microbial-based feed supplements can greatly improve animal immunity and digestive efficacy, not only making it possible to reduce reliance on chemotherapeutics, including antibiotics as well as synthetic growth promoters (Windisch et al., 2008; Zeng et al., 2015), but also boosting animal welfare and consumer health perceptions.

The purpose of this review is to provide a comprehensive overview of current advances in the area of new animal nutrition technologies and their potential impact on productivity improvements and sustainability. The article is structured by tackling recent trends in feed additive technologies, then it continues with information regarding precision feeding and smart technology applications. Other sections deal with the effects of innovative integration on animal productivity, environmental sustainability, and the recent reviews have highlighted the economic importance of creative interplay in this direction (Palani, 2025a; Palani, 2025b), economic and social factors, and potential enabling conditions. Finally, the review highlights current knowledge gaps and suggests directions for further investigations that are pivotal to achieve a full exploitation of these technologies.

Emerging Feed Additive Technologies

Novel feed additive technologies are gaining increased attention due to their significant ability in increasing livestock productivity, maintaining animal health, and managing environmental footprint. These are phytogenic feed additives originated from plants such as essential oils, tannins, and saponins have been popular because of their antimicrobial effects, antioxidant properties along with digestion-promoting features. There is evidence showing that plant essential oils (EO) including thymol, carvacrol, or cinnamaldehyde improved animal performance and efficiency of feed utilization by modifying gut microbiota modulation/nutrient digestibility (Zeng et al.,2015; Abdulla & Ezzadin, 2023; Mhamad & Palani, 2025).

Likewise, the tannins derived from plants such as chestnut and quebracho reduce ruminal methane emissions effectively and prevent premature degradation of dietary proteins in the rumen with increased efficiency to utilize nitrogen compounds (Patra & Saxena, 2011). Saponins mainly present in yucca and quillaja plants have been well documented to reduce ammonia production, protozoal number of the rumen with concomitant increase availability for digestive enzymes such as amylase without exerting adverse effects on animal growth or activity which is an added advantage over antibiotic use (Cheeke, 2000). Probiotics together with prebiotics belong to the most important of emerging feed additives in order to enhance gut health and immune responses.

Probiotics, which mainly consist of beneficial bacteria e.g., Lactobacillus, Bifidobacterium, and Bacillus species, induce intestinal microbiota stability in addition to modulation of gut barrier functions leading to better health status and productive performance in livestock (Markowiak & Śliżewska, 2018). Prebiotics, often referred to as non-digestible oligosaccharides, selectively enhance growth of beneficial microflora in the gut and act synergistically with probiotics for sustained homeostasis of gut which ultimately leads to reduction in incidences of gastrointestinal diseases along with effect on performance (Uyeno et al., 2015). Feed enzymes, such as phytases, xylanases, β-glucanase, and protease are widely used to enhance nutrient digestibility and utilization efficiency. Phytase increases the utilization of P in plant-based diets and thus decreases the amount of phosphorus excreted into the environment (Adeola & Cowieson, 2011). Xylanase and β-glucanase cause hydrolysis of NSP, thus benefitting energy and nutrient intake by animals (Bedford & Cowieson, 2012). The supplementation of these enzymes in monogastric animal feed is a potential solution to the cost and environmental problems concerning feeds. Nanotechnology feed additives represent a new generation of animal nutrition that aims to use nanoparticles as deliver and increase bioavailability for specific nutrients. The

mineral antioxidants of nanoparticles, e.g., zinc, selenium, and copper are readily absorbed by the body with higher bioavailability than common forms available for animal feeding; thus it could greatly improve growth performance and immunity without as much excretion in livestock waste to cause fiber ago-pollution (Hill & Li, 2017).

Furthermore, nano-encapsulation technologies provide a barrier for sensitive bioactive compounds such as vitamins and essential oils against environmental stress during feed processing while increasing their efficacy in the animal gastrointestinal tract (Sekhon, 2014). On all, these novel feed additive technologies are promising solutions to address contemporary issues related to livestock production including resource use efficiency as well as animal health and environmental sustainability (Palani et al.,2024). Additional research and development are needed to fully understand the mechanisms of action, assess optimum application rates, long-term safety profiles in different production systems as well as cost-effectiveness when implemented on a broad scale across the range of livestock-producing enterprises.

Precision Feeding and Smart Technologies

Precision livestock farming and smart technologies have recently shifted the paradigm of animal nutrition, leading to substantial improvements in farm productivity as well as health and environmental impact.

Precision feeding means correctly formulating and providing diets exactly matched with the individual animals' or categories of animals' nutrient requirements. This practice is beneficial for feed efficiency, nutrient wastage, and may also contribute to reducing the environmental pollution associated with over-excretion of nutrients (Pomar & Remus, 2019; Palani et al.,2022). The main advantages of precise feeding management are lower feed costs, increased growth rates and productivity in the animals, and less weaning weight (Tedeschi & Fox, 2020) as well as minimized environmental impacts based on improving nutrient use efficiency.

A real-time monitoring system is a key element in precision feeding practices, which allows the observation of animals' performance and health conditions as well as their eating behaviors. Tools are available that allow the detailed monitoring of feed intake, animal weight, and rumen health as well as activity-based records with technologies such as automated feeding stations, wearable sensors, or RFID (Radio Frequency Identification) systems. This information allows live real-time adjustments to feed composition and management, leading to improvements in both FCR as well as animal welfare (Rutten et al., 2013).

Incorporating AI and IoT into livestock feeding management has revolutionized the old-school methods, providing predictive analysis and smart automation. Large datasets from IoT feeders, air or water quality sensors, and cameras are analyzed by AI-driven algorithms to predict an optimal feeding regime as well as early disease signs in real time, adjust diet composition dynamically according to environmental or physiological factors (Neethirajan 2020). Environmental monitoring—including temperature, humidity, and air quality—as well as animal-specific measures are collected in real time by grid sensors to help ensure livestock receive diets that are carefully formulated for immediate nutritional requirements.

Precision feeding technologies are particularly prevalent in dairy and beef cattle production. Precision feeding in dairy farming prescribes the supply of nutrient needs to cows according to lactation stage and genetic potential as well as individual health conditions, leading to improved milk yields and higher quality with less nutrient discharge into the environment (Bach 2021). In the same way, precision feeding in beef cattle not only improves performance of growth, carcass quality, and feed efficiency but also

personalizes nutrients to the animal's requirements, which leads toward a profitable industry with sustainability (Tedeschi & Fox, 2020).

In general, the combination of precision feeding in concert with smart technologies greatly promotes animal nutrition by increasing efficiency and reducing costs as well as improving animal welfare and environmental sustainability. Future studies should pay attention to the improvement of such technologies, overcoming barriers, and demonstrating economic/environmental benefits over time with different livestock systems.

Role in Animal Productivity

could mean anything from improving nutrient utilization to animal health, or the taste of animal products. In addition to improving flavor and extending shelf life, innovative feed additives such as exogenous extracts with their characteristic activity on microorganisms can thus simultaneously enhance nutrient utilization. For example, factors, phytogens, which are probiotics in advance and prebiotics as well as enzymes that are specially administered, have been shown to have a significant effect on animal growth and milk production and feed efficiency for cattle-based diets. They also make a difference in the overall performance results of livestock.

To feed additives such as essential oils, tannins, and saponins, animals respond positively (Abdulla & Ezzadin 2023) They'll increase both body weight gain as well as how easily converted feed is into growth, stabilize digestive mechanisms and flora for better enzyme release and nutrient uptake from the diet. Essential oils such as thymol, sweet marjoram, and several others not only improve feed efficiency but also significantly increase milk yield and quality by promoting digestive enzyme secretion. In addition, they stabilize rumen fermentation—even under low pH conditions caused by increased H+ ion levels in the stomach (Zeng et al., 2015).

Tannins and saponins decrease ruminal methane production and NADH2 concentrations, thereby increasing nutrient availability and energy retention to support growth or milk production (Patra & Saxena, 2011; Alwan et al., 2018a; Alwan et al., 2018b). In addition to stabilizing the intestinal flora, as well as increasing resistance to infection by pathogens and improving nutrient uptake, probiotics and prebiotics also enhance livestock productivity in general (Markowiak & Śliżewska, 2018; Uyeno et al., 2015). For example, animals fed probiotics have both larger calves and better milk production, as well as improved feed use efficiency which can be credited to the organism's better gastrointestinal health and nutrient absorption (Markowiak & Śliżewska, 2018).

Foods from plants can now be utilized more efficiently by livestock thanks to the addition of feed enzymes, particularly phytases, xylanases, and proteases. Added phytase can liberate plant-based phosphorus from phytate, reducing the amount of dietary phosphorus required and the volume of pollution released so as to improve growth performance of livestock and bone mineralization in animals (Adeola & Cowieson, 2011). Similarly, enzymes like xylanases and β-glucanases improve available energy by degrading complex dietary fiber, enabling higher rates of growth and productivity (Bedford & Cowieson, 2012).

These newly conceived feed-management alternatives are also beneficial to animal health and resistance. For example, at present, feed additives like botanicals have strong and potent antioxidant and anti-inflammatory effects on animals. They reduce oxidative stress and enhance the resilience of livestock against diseases, as well (Palani et al.,2025; Windisch et al., 2008). Probiotic feed enhancement promotes animal immune responses, reduces stomach complaints, and raises overall herd health in farms with the result of lower reliance on antibiotics (Markowiak & Śliżewska, 2018).

Besides performance and health, such modern technologies also exert significant effects on the quality of animal products derived from them as meat, milk, eggs, wool, and so forth. Feed additives such as phytogene, probiotics mean life that is a flavor treatment for feed sources will modify the taste, tempting people to eat more fat-rich foods with greater pleasure even while the intake of animal protein remains low. In this scenario, milk obtained from animals eating enhanced diets with better content shows up also. It has, for example, a higher protein content for the muscular tissues; higher levels of healthy fatty acids and conjugated linoleic acid; less detrimental fat in both forms (3- and 9- cis); greater potassium to maintain cellular flexibility on an energy-depleted schedule and drop adjustments in blood pressure from sitting too long in any one place (Tedeschi & Fox, 2020).

Similarly, eggs from poultry consuming probiotic and enzyme-supplemented diets display better shell quality, nutrient density, and market acceptance among consumers (Markowiak & Śliżewska, 2018). In a word, besides boosting L.S. of life and health for livestock all over the country, the new methods of raising the livestock and enhancing their nutritional quality as products of the farm will get cold-shouldered to no one willfully interested in food.

Environmental Impacts and Sustainability

New feed additive technologies play a major role in contributing to environmental sustainability through the reduction of greenhouse gas emissions, better utilization of resources (efficiency), animal waste management, and the achievement of sustainable agriculture objectives. Livestock systems are an important contributor to GHG (greenhouse gases), with CH_4, N_2O, and CO_2 being the most significant among those released from this source (Palani et al.,2019) Advanced feed supplements like phytogenic compounds, enzymes, and probiotics have potential for abating these emissions efficiently.

Phytogenic feed additives such as tannins and essential oils can significantly reduce enteric methane emissions by their effects on the modulation of ruminal microbial populations, which may result in improvements of nutrient utilization efficiency (Patra & Saxena, 2011; Zeng et al., 2015). Enzymes, such as phytases, also reduce environmental eutrophication (both water and soil) and decrease the relative impact of diets on the environment by reducing phosphorus excretion (Adeola & Cowieson, 2011). Resource efficiency gains also represent another strong environmental benefit. Precision feeding strategies and enzyme provision improve the digestibility and use of nutrients, thereby reducing feed required (including associated inputs such as water, energy, or land) significantly (Tedeschi & Fox, 2020; Pomar & Remus, 2019). If nutrient supply is perfectly aligned to animal needs, the feed value of resources will be maximized, reducing production costs and environmental footprints (Pomar & Remus, 2019).

Proper disposal of animal waste is essential to reduce environmental influence, especially nitrogen and phosphorus excretion. Feed additives such as phytases and innovative probiotics can decrease excretion of nutrients, thus reducing nutrient washout from soil (Adeola & Cowieson, 2011; Markowiak & Śliżewska, 2018). Supplementation with phytase reduces phosphorus requirement of the diet, leading to a remarkable decrease in excretion into the environment (Adeola & Cowieson, 2011). Probiotic administration also enhances gut integrity and nutrient utilization, which decreases fecal nitrogen/phosphorus excretion and the resulting negative impact on the environment (Markowiak & Śliżewska, 2018).

Enhancing the advanced feed technologies offers a strong alignment with global Sustainable Development Goals (SDGs), particularly focusing on responsible consumption and production, stated in Goal 12, climate action which is described under Goal 13, as well as life on land mentioned under Goal 15 of SDG 14 countries even ensuring sustainable

agriculture (FAO, 2019). It is essential to integrate sustainable feed additive technologies that uphold the aforementioned objectives by facilitating increased productivity and reduced emissions, smart use of resources, and better animal welfare, contributing to long-term sustainability in residences with resilience along livestock production systems.

Economic and Social Considerations

considerable economic and social consequences that may be good or bad for husbandmen. A vital factor for producers pondering these pioneering answers is to conduct a comprehensive cost-benefit analysis.

However, although the initial cost of introducing advanced feeding technologies like precision feeding systems, probiotics, enzymes, and phytogenic additives is high, such technologies are capable of bringing in substantial long-term economic returns. Not only so, costs of veterinary medicine are reduced through enhanced feed utilization return on retinal pigment studies conducted in swine; negative impacts of environmental regulations also decreased (Pomar & Remus, 2019; Tedeschi & Fox, 2020). Studies have shown that precision feeding results in a waste of less feed and lower overhead, and its rate of return on investment (ROI) is quite attractive in terms of nutrient utilization efficiency (Pomar & Remus, 2019). Yet, offsetting these advantages are many challenges facing the adoption of emerging technologies from economic and social perspectives. High initial investment costs, the need for basic infrastructure improvements, and knowledge and training all may tend to make it difficult to put into practice new technologies, especially for small-scale farmers or producers that do not have the economic resources of larger fishpond farmers (Neethirajan, 2020). As well, differences in regulatory structures and little access to finance make the process of pushing forward widespread adaptation still more complicated.

Indeed, the acceptance by consumers and market trends are intimately linked to the takeoff of novel animal nutrition technologies. Consumers are increasingly demanding that animal products be raised sustainably, ethically, and without antibiotics or artificial growth promoters. Products from animals which have been fed on innovative feed additives, particularly phytogenic compounds, probiotics, and enzymes, all show upscale nutritional profiles and safer characteristics in food science terms these days. As a result, they fit well with modern concerns about food safety and consumer preferences generally speaking (Palani, 2025a; Palani, 2025b; Zeng et al., 2015; Markowiak & Śliżewska, 2018). Hence, future markets for producers taking up these techniques are broadening as awareness among consumers of issues like the environment and animal welfare grows.From the social aspects, positive effects result for rural communities that adopt these new feed technologies. Namely, the productivity of farms goes up, they make more profit and are sustainable. Applicants for jobs can find themselves in a better position after university, while the relative poverty of agricultural communities improves. However, to make a success of it, the necessary requirements are backing up technology integration with education and training and community initiatives for local farmer liaison services (Neethirajan, 2020).

In conclusion, emerging technologies must be adopted while overcoming economic obstacles, regulatory problems, and education. Targeted support coupled with wide diffusion of knowledge will enable these technologies to bring out considerable economic returns, sustainability, and even pro-poor results in rural communities.

Challenges and Barriers

Innovative feed additive technologies for use in animal nutrition, especially the cost of getting started (set-up costs), needs as regards infrastructure and technical knowledge/expertise or regulatory aspects.

While precision feeding systems, probiotics, and similar products or technologies—as can enzymes—may impart significant financial advantages on producers who use them, the cost burden they impose upfront is considerable. And while the unique features of feed additives are usually molecular in nature, a significant investment for specialized equipment and/or feed facilities will be necessary, especially among small producers located in remote areas (Neethirajan, 2020; Pomar & Remus, 2019). Additionally, technical skills and specialist knowledge are needed. The use of these nutritional technologies also requires appropriate operatives with skills for animal nutrition, data management, and adaptability to new technology. Without the right expertise, producers may achieve less than optimal results: technologies are under-utilized or used incorrectly, and their benefits for society as well as economic viability decline (Abdulla & Ezzadin 2023) (Neethirajan, 2020).

Regulations, legislation policies are also very oppressive. To get new feed additives or nutritional technologies on the market is a difficult, long, and expensive journey that must involve approvals by many people who know nothing about them. Regulatory requirements in various regions are different, and few people manage to get products for international markets that will be accepted there. In order to manufacture according to these legislative standards, the further capital required is another economic burden on businesses (Adeola & Cowieson, 2011).

Lastly, general use necessitates broad training, the availability of extension and technology transfer on a large scale. A strong training programme and targeted extension support are necessary to achieve that farmers (and other parties) clearly learn how they can make use of new technology. Training programs will also help farmers, i.e., to impart knowledge and skill deficiency, develop a positive attitude towards such advanced technology adoption and practice, especially for the small-scale lean resource farmers (Neethirajan, 2020; Pomar & Remus, 2019).

Finally, the challenges—economic, technological/regulatory, and educational ones—must be addressed to ensure successful integration as well as widespread use of new feed additive technologies resulting in enhanced productivity, sustainability, and economic resilience in animal production.

Future Research Directions

Innovative feed additive technologies for use in animal nutrition, especially the cost of getting started (set-up costs), needs as regards infrastructure and technical knowledge/expertise or regulatory aspects.

While precision feeding systems, probiotics, and similar products or technologies—as can enzymes—may impart significant financial advantages on producers who use them, the cost burden they impose upfront is considerable. And while the unique features of feed additives are usually molecular in nature, a significant investment for specialized equipment and/or feed facilities will be necessary, especially among small producers located in remote areas (Neethirajan, 2020; Pomar & Remus, 2019).

Additionally, technical skills and specialist knowledge are needed. The use of these nutritional technologies also requires appropriate operatives with skills for animal nutrition, data management, and adaptability to new technology. Without the right expertise, producers may achieve less than optimal results: technologies are under-utilized or used incorrectly, and their benefits for society as well as economic viability decline (Neethirajan, 2020). Regulations, legislation policies are also very oppressive. To get new feed additives or nutritional technologies on the market is a difficult, long, and expensive journey that must involve approvals by many people who know nothing about them. Regulatory requirements in various regions are different, and few people manage to get

products for international markets that will be accepted there. In order to manufacture according to these legislative standards, the further capital required is another economic burden on businesses (Adeola & Cowieson, 2011).

Lastly, general use necessitates broad training, the availability of extension and technology transfer on a large scale. A strong training programme and targeted extension support are necessary to achieve that farmers (and other parties) clearly learn how they can make use of new technology. Training programs will also help farmers, i.e., to impart knowledge and skill deficiency, develop a positive attitude towards such advanced technology adoption and practice, especially for the small-scale lean resource farmers (Neethirajan, 2020; Pomar & Remus, 2019).

Finally, the challenges—economic, technological/regulatory, and educational ones—must be addressed to ensure successful integration as well as widespread use of new feed additive technologies resulting in enhanced productivity, sustainability, and economic resilience in animal production.

Conclusions and Recommendations

Novel feed additive-based technologies and precision nutritional systems represent feasible means to enhance livestock productivity, support animal welfare, and reduce environmental harm. These developments, ranging from natural bioactive compounds to sophisticated smart feeding systems, also have an impact on the overall sustainability and efficiency of agricultural practices.

In this sense, it is important to note that the strategies must be adjusted according to regional peculiarities and breed characteristics of local animals, as well as concerning economic analysis. Educational efforts to increase the level of technical knowledge and awareness among farmers and advisors must be accented. Couric is right to be leery of the use of technology for its own sake, but policymakers must also invest in infrastructure that supports innovation and put into place a regulatory structure that allows new technologies to come online safely. Further research is required to develop this work and assess the long-term effects of these inventions in real farm conditions.

The livestock sector can meet future food security challenges and contribute to sustainability objectives by embracing a more holistic perspective that considers scientific advances, economic viability, as well as environmental responsibility.

References

1. Abdulla, M. M., & Ezzadin, I. N. (2023). Effect of using some medicinal plant oils on productive performance of broilers. Journal of Medicinal and Industrial Plants, 1(1), 67–77. http://medip.uokirkuk.edu.iq/index.php/medip
2. Adeola, O., & Cowieson, A. J. (2011). Board-invited review: Opportunities and challenges in using exogenous enzymes to improve nonruminant animal production. Journal of Animal Science, 89(10), 3189-3218. https://doi.org/10.2527/jas.2010-3715
3. Al-Obaidy, M. H. A., Mohammed, S. J., Baker, A. G. & Palani, Z. M. R. (2022). Effect Cannabis Oil on the Growth Performanceand some Biochemical Indicators in Blood Serum of MaleLambs Awassi Breed Sheep. Journal of Current Research on Engineering, Science and Technology, 8 (2), 181-186.
4. Alwan, A. S., Majid, A. F., & Ismail, H. I. (2018a). The effect of using some hormonal treatments on some reproductive performance traits in Awassi ewes. *Kirkuk University Journal for Agricultural Sciences, 9*(4), 17–23.

5. Alwan, A. S., Majid, A. F., & Ismail, H. I. (2018b). The effect of a hormonal program on some physiological and biochemical blood traits in Awassi ewes. *Kirkuk University Journal for Agricultural Sciences*, *9*(4), 52–59.
6. Bach, A. (2021). Precision feeding to increase efficiency for milk production. Animal Production Science, 61(6), 554-559. https://doi.org/10.1071/AN20402
7. Bedford, M. R., & Cowieson, A. J. (2012). Exogenous enzymes and their effects on intestinal microbiology. Animal Feed Science and Technology, 173(1-2), 76-85. https://doi.org/10.1016/j.anifeedsci.2011.12.018
8. Cheeke, P. R. (2000). Actual and potential applications of Yucca schidigera and Quillaja saponaria saponins in human and animal nutrition. Journal of Animal Science, 77(E-Suppl), 1-10. https://doi.org/10.2527/jas2000.77E-Suppl1x
9. FAO. (2019). Sustainable Development Goals: Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/sustainable-development-goals/en/
10. Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., ... & Tempio, G. (2013). Tackling climate change through livestock–A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO).
11. Hill, E. K., & Li, J. (2017). Current and future prospects of nanotechnology in animal production. Journal of Animal Science and Biotechnology, 8, 26. https://doi.org/10.1186/s40104-017-0157-5
12. Makkar, H. P. S., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. Animal Feed Science and Technology, 197, 1-33. https://doi.org/10.1016/j.anifeedsci.2014.07.008
13. Markowiak, P., & Śliżewska, K. (2018). The role of probiotics, prebiotics, and synbiotics in animal nutrition. Gut Pathogens, 10, 21. https://doi.org/10.1186/s13099-018-0250-0
14. Mhamad, H. J., & Palani, Z. M. R. . (2025). Pharmacological Active Crocin (Antioxidant) in Saffron: A Review. *Spanish Journal of Innovation and Integrity*, *38*, 8–17. Retrieved from https://sjii.es/index.php/journal/article/view/169
15. Mhamad, H. J., Palani, Z. M. R., & AL-Zubaidy, A. . (2025). Investigation of the Chemical Compounds, Antioxidant Effect and Therapeutic Properties of Crocus sativus L. (Iridaceae): A Review. *Indonesian Journal of Innovation and Applied Sciences (IJIAS)*, *5*(1), 89-98. https://doi.org/10.47540/ijias.v5i1.1829
16. Mohamed, N. (2025). Response of two promising cultivars of bread wheat (Triticum aestivum L.) to conservation agriculture under rainfed irrigation in a moderate rainfall area in Nineveh Governorate. Journal of Medicinal and Industrial Plant Sciences, 3(2), 1-14. doi: 10.32894/MEDIP.25.3.2.1
17. Nasir, Z., & Grashorn, M. A. (2010). Effects of intermittent application of different Echinacea purpurea juices on broiler performance and some blood indices. Poultry Science, 89(6), 1182-1187. https://doi.org/10.3382/ps.2009-00520
18. Neethirajan, S. (2020). The role of sensors, big data, and machine learning in modern animal farming. Sensing and Bio-Sensing Research, 29, 100367. https://doi.org/10.1016/j.sbsr.2020.100367
19. Neethirajan, S. (2020). The role of sensors, big data, and machine learning in modern animal farming. Sensing and Bio-Sensing Research, 29, 100367. https://doi.org/10.1016/j.sbsr.2020.100367

20. Neethirajan, S. (2020). The role of sensors, big data, and machine learning in modern animal farming. Sensing and Bio-Sensing Research, 29, 100367. https://doi.org/10.1016/j.sbsr.2020.100367

21. Palani, P. M. R. . (2025a). Residential Crisis in Iraq: The Current Trends and Future Prospectus: A Review. *Spanish Journal of Innovation and Integrity*, *38*, 121–128. Retrieved from https://sjii.es/index.php/journal/article/view/185

22. Palani, P. M. R. . (2025b). The Relationship of International Loans to Credit Wall (Worthiness): A Review. *Spanish Journal of Innovation and Integrity*, *38*, 1–7. Retrieved from https://sjii.es/index.php/journal/article/view/168

23. Palani, Z. M. R. ., Zinalabidin, M. M. ., Hussein, Z. A. ., Farhan, M. ., Ali, M. ., Mohammed, N. ., … Walid, A. . (2025). Behavioral Responses of Awassi Ewes to Dietary Cannabis Seed Powder Supplementation. Spanish Journal of Innovation and Integrity, 41, 222–231. Retrieved from https://www.sjii.es/index.php/journal/article/view/446

24. Palani, Z. M. R. K., Khalil, W. A., Kutaibani, H. E. I., & Amin, F. A. M. (2023). Effect of Selenium and Zinc Supplementation Alone and Their Mixture on the Carcass Characteristics of Kurdi Lambs. Syrian Journal of Agricultural Research – SJAR, 10(2), 129-136.

25. Palani, Z. M. R. K., Kutaibani, H. E. I., & Amin, F. A. M. (2018). Changes in Some Blood Biochemical Indicators in Kurdi Rams Response of Selenium and Zinc Supplements. SJAR, 5(4), 87-96.

26. Palani, Z. M. R., Ameen, G. W., & Shekhani, D. N. M. (2025). The Role of Lead and Molybdenum and Their Effects on Oxidative Stress in Ruminant Animals: Subject Review. Nabatia, 13(2), 104–115. https://doi.org/10.21070/nabatia.v13i2.1665

27. Palani, Z. M. R., Hamasalim, H. J. ., Abdualmajeed, O. M. ., Baqer, J. M. ., Omer, M. E. A. ., Mohammed, H. N. ., & Bchkol, D. H. K. . (2024). Biochemical Changes in Blood Serum after Selenium and Zinc Doses and their Effect on the Health and Environment of Kurdi Sheep in Kurdistan Region. Indonesian Journal of Social and Environmental Issues (IJSEI), 5(3), 299-305. https://doi.org/10.47540/ijsei.v5i3.1674.

28. Palani, Z. M. R., Khalil, W.A, Kutaibani, H. E. I. ., & Amin, F. A. M. . (2024). Effect of Sodium Selenite and Zinc Sulphate on the Weight, Size, Seminal Fluid Traits, and Histological Changes of the Testis and Epididymis in Kurdi Rams. Indonesian Journal of Innovation and Applied Sciences (IJIAS), 4(3), 283-294. https://doi.org/10.47540/ijias.v4i3.1672.

29. Palani, Z.M.R.K., Al-Jaf, H. I. and Raheem, S. M.2019. Effect of addition of Selenium to Kurdi Sheep and its interactions with some necessary and Toxic Elements on Health and The Environment.Plant Archives. Vol. 19 No. 2, pp. 3963-3970.

30. Patra, A. K., & Saxena, J. (2011). Exploitation of dietary tannins to improve rumen metabolism and ruminant nutrition. Journal of the Science of Food and Agriculture, 91(1), 24-37. https://doi.org/10.1002/jsfa.4152

31. Place, S. E., & Mitloehner, F. M. (2014). Invited review: Contemporary environmental issues: A review of the dairy industry's role in climate change and air quality and the potential of mitigation through improved production efficiency. Journal of Dairy Science, 97(8), 4300-4322. https://doi.org/10.3168/jds.2013-7324

32. Pomar, C., & Remus, A. (2019). Precision pig feeding: A breakthrough toward sustainability. Animal Frontiers, 9(2), 52-59. https://doi.org/10.1093/af/vfz006

33. Pomar, C., & Remus, A. (2019). Precision pig feeding: A breakthrough toward sustainability. Animal Frontiers, 9(2), 52-59. https://doi.org/10.1093/af/vfz006

34. Rutten, C. J., Velthuis, A. G. J., Steeneveld, W., & Hogeveen, H. (2013). Invited review: sensors to support health management on dairy farms. Journal of Dairy Science, 96(4), 1928-1952. https://doi.org/10.3168/jds.2012-6107

35. Sekhon, B. S. (2014). Nanotechnology in agri-food production: an overview. Nanotechnology, Science and Applications, 7, 31-53. https://doi.org/10.2147/NSA.S39406

36. Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & de Haan, C. (2006). Livestock's long shadow: Environmental issues and options. Food and Agriculture Organization of the United Nations (FAO).

37. Tedeschi, L. O., & Fox, D. G. (2020). The Ruminant Nutrition System: An applied model for predicting nutrient requirements and feed utilization in ruminants (2nd ed.). XanEdu Publishing.

38. Uyeno, Y., Shigemori, S., & Shimosato, T. (2015). Effect of probiotics/prebiotics on cattle health and productivity. Microbes and Environments, 30(2), 126-132. https://doi.org/10.1264/jsme2.ME14176

39. Windisch, W., Schedle, K., Plitzner, C., & Kroismayr, A. (2008). Use of phytogenic products as feed additives for swine and poultry. Journal of Animal Science, 86(suppl_14), E140-E148. https://doi.org/10.2527/jas.2007-0459

40. Zeng, Z., Zhang, S., Wang, H., & Piao, X. (2015). Essential oil and aromatic plants as feed additives in non-ruminant nutrition: a review. Journal of Animal Science and Biotechnology, 6(1), 7. https://doi.org/10.1186/s40104-015-0004-5