REVIEW ARTICLE Asian Journal of Dairy and Food Research, Volume 45 Issue 1: 12-20 (February 2026)

Advances and Challenges in Modern Dairy Farming: A Comprehensive Review

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10.18805/ajdfr.DR-2319

ABSTRACT

Modern dairy farming has seen significant advancements driven by technology, but challenges remain. Automated milking systems and precision agriculture have enhanced productivity and efficiency. However, small-scale farmers continue to struggle with economic instability, limited resources and access to technology. These factors complicate the industry's overall development and growth. This review synthesizes data from scientific literature, industry reports and case studies to assess the current state of the dairy farming industry. It provides a comprehensive examination of technological innovations, socio-economic issues and environmental concerns. The data collected allows for an in-depth analysis of both the positive outcomes and ongoing challenges in the field. Technological advancements have brought clear improvements in efficiency, yet socio-economic inequalities persist, particularly for small-scale farmers. Economic volatility and disparities in resource access continue to hinder growth. Environmental sustainability has emerged as a crucial concern, with increased emphasis on adopting eco-conscious farming practices. The review highlights the need for collective action, including better communication, proactive community engagement and shared commitments to sustainable practices. For the industry to remain viable, it must prioritize both technological progress and socio-economic equity, ensuring a more inclusive and environmentally responsible future for dairy farming.

Key words: Dairy farming, Environmental sustainability, Socio-economic challenges, Sustainable development.

Dairy farming is vital for global food production and livelihoods. Over the years, technological advancements have transformed the industry. Genetic selection and breeding programs have led to high-yielding dairy cattle, improving milk production and quality. Artificial insemination and genomic technologies have enhanced breeding efficiency (Cardoso *et al*., 2016). Environmental sustainability is a growing concern. Manure management, greenhouse gas emissions and water usage are key challenges. Farmers are adopting practices like anaerobic digestion, nutrient management and renewable energy to reduce their environmental impact. Despite advancements, the industry faces challenges related to animal welfare, antimicrobial resistance and consumer demand for sustainable, ethically produced products. Changes in animal husbandry have encouraged specialization, mechanization and intensification (Danne and Musshoff, 2017). Over the past 50 years, there has been significant growth in cattle husbandry. This has led to higher yields and better feed conversion efficiency (Boogaard *et al*., 2011). The adoption of food safety and quality standards has improved safety, reduced costs and lowered manual labor (Britt *et al*., 2018; Kim and AlZubi, 2024; Cho, 2024). While dairy farming has made remarkable progress, it must address ongoing socio-economic and environmental challenges for sustainable growth.

With 24 per cent of the world's milk produced, India is now the world's biggest milk producer.

India consumes 427 grams of milk per person per year, compared to the global average of 322 grams. Fig 1 shows the number of milk cows worldwide by nation in 2023. Collectively, account for 53.08% of milk output worldwide. Goat milk contributes 3%, cow milk makes up 52% of the total milk produced and buffalo milk makes up 45%). In conclusion, this comprehensive review aims to provide a holistic understanding of the advances and challenges in modern dairy farming. By exploring various aspects of dairy production, it highlights the need for continued research, innovation and sustainable practices to ensure the long-term viability and success of the dairy industry.

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How to cite this article: Raghuramapatruni, R. (2026). Advances and Challenges in Modern Dairy Farming: A Comprehensive Review. *Asian Journal of Dairy and Food Research.* **45(1):** 12-20. doi: 10.18805/ajdfr.DR-2319.

Submitted: 17-02-2025 **Accepted:** 29-12-2025 **Online:** 10-01-2026

Technological innovations in dairy farm management

Significant technical advancements have been seen in the fluid milk processing sector over the past 20 years, leading to notable improvements in every unit operation, including

packaging, pasteurization, homogenization, separation and standardization.

Big data

Big data refers to data sets too large or complex for conventional processing tools (De Mauro *et al*., 2016). It is transforming farming through a pull-push mechanism (Wolfert *et al*., 2014). Big data addresses global challenges such as food safety, security, sustainability and efficiency by providing valuable insights. A wide range of devices and items with wireless connectivity are generating vast amounts of real-time data (Wolfert *et al*., 2014; Ganesan, 2013). Analytics play a crucial role in making sense of this data. Many startups are developing applications in risk management, predictive modeling and sensor deployment (Wolfert *et al*., 2017).

Cloud computing and Edge

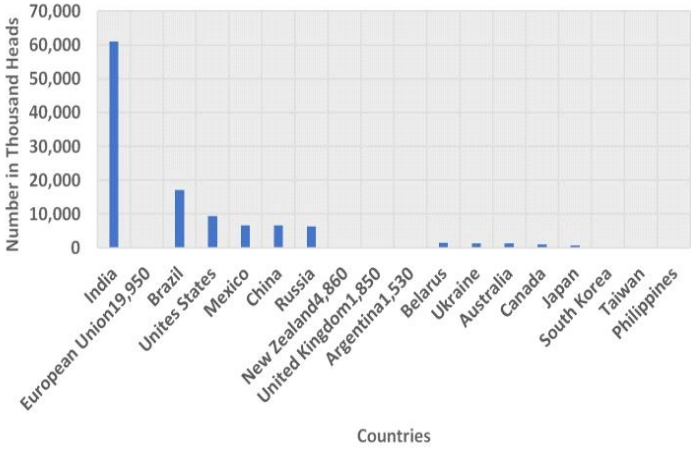
Agriculture systems can incorporate computing platforms; however, these platforms are not designed to handle large amounts of real-time machine-generated data (MG). Additionally, scaling them up to the degree necessary for highly iterative, data-driven machine learning model and algorithm training is costly and challenging (Min *et al*., 2024). Platforms for cloud computing are ideal for these kinds of tasks because of their flexibility and scalability, but to do this, a lot of MG data must be sent to the cloud (Carvalho *et al*., 2019). However, a lot of the most current user-centric Internet of Things applications are latency-sensitive or need real-time data analysis and decision-making; in these situations, cloud computing could not be used because of latency issues (Zamora-Izquierdo *et al*., 2019).

Milk monitoring and supply chain

The dairy industry currently assesses milk solids percentage through samples collected during milk collection from farms (Nyokabi *et al*., 2021). IoT can enhance dairy operations by providing real-time milk quality monitoring using sensors that distinguish between milk qualities (Saravanan *et al*., 2021). IoT's automation and monitoring capabilities improve supply chain efficiency, product quality and productivity. Real-time monitoring helps reduce milk rejection at processing facilities, identify premium milk and improve milk supply forecasting and production scheduling (Patil *et al*., 2021). Studies show that visible light, near-infrared (NIR) and infrared (IR) spectroscopy are effective for assessing milk quality (Gastélum-Barrios *et al*., 2020). However, NIR-based milk quality monitors are costly and impractical for widespread farm use (Munir *et al*., 2015; Koike *et al*., 2023; Alshahrani, 2024). Recent advancements in affordable biosensors and electrochemical sensors show promise in laboratory milk quality assessments (Poghossian *et al*., 2019; Joshi *et al*., 2015).

Monitoring of feeds

Food plays a crucial role in the nourishment of animals as it governs the quantity of nutrients accessible to the animal to sustain health and enhance productivity (DeVries *et al*., 2003). Deficiency of certain nutrients lowers output and can be damaging to the health of the animals; excessive nutrient supplementation increases feed costs, adds to the nutritional burden on the environment and may be hazardous to human health (Bloch *et al*., 2019). Modern high-yielding cow varieties require a steady supply of grain and fodder. A significant amount of cow feed, meal dietary supplements, antibiotics and other inputs are required for dairy production. India now boasts the highest animal population in the world due to the country's explosive growth in the dairy farming industry over the past several decades (Chizzotti *et al*., 2015). The biggest obstacle to dairy production in India is now a persistent lack of cow feed and poor-quality fodder.



(Source: https://www.statista.com/statistics/869885/global-number-milk-cows-by-country/)

Fig 1: Global milk cow population by country in 2023.

Tracking animal location

Tracking combined with an identifying task and counting the total number of animals who come back after grazing outside may significantly increase the welfare of animals and improve husbandry methods (Foris *et al*., 2019). Efficient farm management and high-quality research both benefit greatly from the recording and monitoring of individual animal behaviors. The basic behaviours of dairy cows typically involve feeding, standing and lying; groups exhibit synchronized sequences of activity and rest (Leliveld and Provolo, 2020). Installing electrical devices and sensors to track animal activity and identify abnormal behavior in animals is becoming more and more popular. Observation directly and video monitoring take a lot of time on many farms when it comes to animal supervision (Melzer *et al*., 2021). More wearable sensors are incorporated in animal studies to capture animal behavior. For example, sleeping time and heat events are tracked using tri-axial accelerometers. Computer systems based on vision that follow animal movement by segmenting images and extracting characteristics from a single camera have taken the position of human inspectors (Veissier *et al*., 2017). Moreover, computer vision analysis performance might be negatively impacted by just using the RGB camera in a barn with dim lighting, a complex background and a dusty environment (Porto *et al*., 2014). Cow position detection is a challenge for vision-based systems; on the other hand, ML-based vision-based systems can assist with cow location detection, but they need extra infrastructure for tracking dairy animals in large spaces like barns (Wurtz *et al*., 2019). Ultra-wideband (UWB)-based real-time location systems provide new possibilities for precisely locating animals in real-time.

Environmental sustainability in dairy farming

Using manure, fertilizers and dairy wastes on land

Eutrophication occurs when excessive nitrogen, particularly phosphorus, is added to streams, rivers and lakes, causing excessive algae growth and reducing oxygen levels for aquatic life. Indicators of eutrophication include fish kills in summer, the loss of oxygen-sensitive species and algal blooms near coasts (Hoorman *et al*., 2008). Elevated nitrogen levels in groundwater and municipal water sources can also cause serious health issues (Showers *et al*., 2008; Bishop *et al*., 2005). Dairy farming, like other animal agricultural practices, can contribute excess nitrogen and phosphorus to water and soil through various methods (Schröder *et al*., 2007). Large farms or those in certain watersheds may exceed the soil's ability to absorb nutrients from manure. Dairy cattle grazing near water bodies can directly expose aquatic ecosystems to nitrogen and phosphorus. Spreading liquid manure before heavy rainfall can also contaminate water sources, especially if manure with high phosphorus levels is used (Rotz *et al*., 2005).

Contributions to the change in climate

Recent reports from the United States Environmental Protection Agency (EPA) (Heath *et al*., 2011), the Food and Agriculture Organization (FAO) of the United Nations (Steinfeld and Wassenaar, 2007) and the United Nations Intergovernmental Panel on Climate Change (IPCC) (Barker *et al*., 2009) have documented the contributions of livestock production generally to climate change on a global and national scale. In contrast to N_2O, which is contributed by manure and urine excretions, CH_4 is released by the intestinal fermentation of beef and dairy cattle as well as through bacterial activities in recently ejected dung (De Klein and Eckard, 2008; Luo and Saggar, 2008). Methane (CH_4) is generated by the anaerobic breakdown processes that take place in manure storage lagoons, the intestinal fermentation of beef and dairy animals and their recently deposited dung. The use of fertilizer for crop and pasture production (Schils *et al*., 2008), the anaerobic and aerobic breakdown of cattle manure in manure storage lagoons and dry waste piles and the spreading of manure slurry on fields (Van der Meer, 2008) are all linked to the release of N_2O in intensive livestock systems. According to a study by Steinfeld and Wassenar (2007), enteric fermentation in the United States is specifically responsible for 71% of the methane emissions from agriculture worldwide (mostly from dairy and beef cattle). According to recent research, dairy cattle are a significant source of nitrogen, accounting for 15% of worldwide nitrogen emissions in the form of NH_3 and N_2O (Oenema *et al*., 2005).

Ammonia volatilization from manure and manure slurry

Up to 70% of the nitrogen in manure can volatilize as ammonia (NH_3). This process has been investigated mostly about liquid manure held in lagoons (from confinement operations) (Jackson *et al*., 2000; Cahoon *et al*., 1999). A 50 km radius around the original lagoon is thought to include up to 50% of the ammonia deposited, according to studies that have observed and modelled this volatilization. However, manure slurry spread on fields and cattle feces left on pasture can also cause nitrogen volatilization (Rotz *et al*., 2002; Rotz *et al*., 2005). The highest levels of nitrogen volatilization occur when livestock are fed a high-protein diet and/or high-protein forage (Soder and Rotz, 2001).

Effects directly on water quality

Allowing pastured cattle access to natural waterbodies can pose a challenge due to their potential to cause physical degradation to the stream bank and shoreline. Moreover, it is well-established that these cattle tend to defaecate after drinking, making the situation even more problematic (Bishop *et al*., 2005; James *et al*., 2007). Runoff from fields, including pastures and crops, can also carry manure into waterbodies; this issue is most noticeable during periods of intense rainfall (Owens and Shipitalo, 2006). Applying manure can also lead to an overabundance of phosphorus in the soil, which can then affect groundwater and surface water bodies. Manure rates and volumes are usually determined by the nitrogen content of the manure, which leads to overapplication of phosphorus (especially if cattle are fed phosphorus in their dietary rations) (Toth *et al*., 2006;

Soupir *et al*., 2006). Fertilizers used to increase fodder production are also linked to the runoff of phosphorus and nitrogen in management-intensive grazing systems.

Genetic advancements in dairy cattle breeding

Traditionally, the primary goal of breeding programs for dairy cattle has been to increase production per unit input. After selective breeding for economically important qualities began, based mostly on phenotypic data, it has more recently turned to genomic selection to produce animals with substantial genetic value. Reproductive methods have been parallel-optimized to spread high-merit genomes (Flint and Woolliams, 2008). The most recent genetic selection techniques have been combined with modern reproductive technology to enhance economically significant features, such as fertility (Berendt *et al*., 2009). Furthermore, certain traits such as early embryo development and conceptus maternal interactions which are crucial for both embryo quality and a successful gestation have also been studied using functional genomic approaches (Mondou *et al*., 2012; Walsh *et al*., 2012).

Advanced genetic value prediction

Genomic selection has had a major influence on the genetic progress of dairy cows. They use genetics to evaluate the artificial intelligence corporation that buys young bulls. According to Wiggans *et al*. (2017), genotyping occurs before a bull or heifer reaches one month of age and a few embryos are genotyped before implantation. Genetic selection (GS) of young animals in dairy cows can be predicted more accurately. Compared to the conventional offspring test structure, which is costly and out of reach for many poor countries, GS may be utilized to evaluate an expanded perspective animal population, increasing the intensity of selection (Matthews *et al*., 2019). Dairy cows and beef cattle make up the majority of genomic predictions in developing nations. These predictions typically use a small reference population (between 500 and 3,000 animals). The use of genetic engineering (GS) is essential to the survival of animal breeding businesses because it reduces generation intervals and boosts genetic gain (Ibtisham *et al*., 2017; Lozada-Soto *et al*., 2021).

Increased ability to heat tolerance

Many tropical and subtropical regions of the world have seen a decline in dairy cattle output due to extreme ambient conditions. Dairy cows produce less milk when the temperature and humidity reach a specific threshold and genetic variety is linked to yield loss. The development of genomic estimated breeding values (GEBV) for heat resistance in dairy cows made it possible for selection to improve heat resistance; genomic selection may be used to improve heat resistance in dairy cows.

To obtain a balanced conclusion, heat tolerance has been incorporated in a multi-trait selection index along with correlations with additional production and functional characteristics and the net economic effect given present and expected future occurrence of heat stress events (Nguyen *et al*., 2016). Genome-wide DNA markers that indicate tolerance to heat stress in a particular cattle population can be used to speed up breeding for heat stress resistance through genomic selection. Utilizing the whole genome as a selection feature, one may search and locate genomic areas that are abundant in genes associated with environmental adaptation, either directly or indirectly (Onzima, 2019). Global studies have shown that genetic selection for heat tolerance (GS) improves the resilience and well-being of dairy cattle, particularly in regions where more frequent and extended heat stress episodes are predicted (Garner *et al*., 2016). The accuracy of the genetic prediction for heat tolerance in the Holstein and Jersey cow breeds, respectively, has been estimated to be 0.39 to 0.57 and 0.44 to 0.61. The predictions imply that GS is a viable method for accelerating genetic advancements in the selection of cattle with increased heat tolerance.

Improved health of dairy cattle

Novel selection factors for dairy cows have been proposed, including resistance to communicable and non-communicable illnesses and environmental adaptation. According to König and May (2019), there is a correlation between the immune response characteristics' genetic origin and the production and function attributes of dairy cows. Placental residual, ketosis, genuine gastro relocation, mastitis and claudication are among the genomic predictions for which there are genomic assessments to determine the genetic risk of certain diseases in dairy cows (Vukasinovic *et al*., 2017). Productivity and health traits have greatly improved after genomics was included in the herd enhancement program. Genetic alterations in characteristics related to milk production have increased by 50-100% (García-Ruiz *et al*., 2016). According to Khatkar *et al*. (2012), the quantitative trait loci (QTL) of milk manufacturing on chromosome 14 and the complete genome are influenced by milk production features on chromosomes 6, 14 and 20. The data from genome analysis expedites the genetic assessment of dairy cows and provides a valuable substitute for the creation of databases that are highly valuable to animal science and novel genome editing technologies (Gutierrez-Reinoso *et al*., 2021).

Increased feed efficiency

Feed has a significant role in the variable costs of dairy farming production and is crucial to the objectives of breeding (Wallén *et al*., 2017). Therefore, increasing feed efficiency has substantial economic implications. A breeding program aimed at genetic improvement may include feed efficiency, which calculates the energy required for milk production, preservation and reproduction. Any genetic improvement program may incorporate feed efficiency into its breeding goals by calculating the energy required for the production of milk, maintenance and reproduction. According to Rahman *et al*. (2021), genomic selection

purely on yield leads to an increase in feed consumption, a greater negative energy balance and increased mobilization of body tissues during lactation. Breeders that employ breeding values can accept the accuracy of genomic predictions since qualities are heritable. Pryce *et al*. (2014) estimated that dry matter input and residual feed intake (RFI) of dairy cows had a genetic predictive accuracy of around 0.4. A genetically complicated attribute, feed efficiency is generally expressed in terms of units of product output, such as the amount of milk produced per unit of feed input. An application of GS might enhance feed efficiency, which is a heritable characteristic. With an extensive reference population, dairy cattle may therefore effectively apply GS to improve the efficiency of feed (Brito *et al*., 2020).

Socio-economic dynamics of dairy farming

Small and marginal farmers' earnings are supplemented by dairy farming (Jaiswal *et al*., 2018). It significantly increases agricultural households' discretionary income (Singh and Joshi, 2008). The dairy industry promotes sustainability and ecological balance in addition to creating job opportunities (Dhanabalan, 2009). Because of factors including growing urbanization, rising per capita income and an ageing population, emerging nations are seeing an increase in the demand for food originating from animals (Willaarts *et al*., 2013). According to Abubakar *et al*. (2012), using cow dung for the creation of bio-compost, vermin-compost and biogas requires sufficient attention in addition to increased productivity or output. Another possible source for biogas generation is cow manure from slaughterhouses (Johnson *et al*., 2018).

Challenges in dairy farming

According to Basic Animal Husbandry Statistics 2019, the Government of India, India is the world's largest producer of milk, with 187.7 million tons produced in 2018-19. The nation has its processes for making, processing, marketing and drinking milk. Tropical and temperate climates have presented additional hurdles to Indian dairy production, in addition to the lack of quality breeds and commercial size. In Western India's arid regions, the circumstances worsen (Kant *et al*., 2015). The following are a few significant obstacles that the Indian dairy industry faces.

Infrastructure

The village level does not have a sufficient number of cooling centers. According to Meena *et al*. (2017), there is also no effective cold chain distribution network. In addition, sufficient spaces for production and infrastructure are required for value-added products.

System of breeding

Experts have determined that there are two problems concerning Indian cattle breeds: (1) most of them take a long time to mature and (2) most of them have longer calving intervals. Animal performance efficiency is impacted by these parameters.

Feed and fodder

A decline in grazing land is the primary cause of the shortage of feed and fodder. Animals that are not productive also result in an additional large demand for feed and fodder. Small-scale dairy farmers, marginal producers or unemployed laborers cannot afford to purchase pricey feed and fodder. The lack of mineral combination supplements also contributes to metabolic issues and diseases with mineral deficiencies. The dairy business makes less money when feeding costs are higher (Moran, 2005).

The selling price of farmers' milk

It is commonly known that the existence of middlemen and sellers in the manufacturing chain prevents milk farmers from receiving a fair price for their products. The WTO's restrictions on imports of milk and dairy goods may make things difficult for Indian farmers. Therefore, for farmers to survive, costs must be reduced in both milk production and processing. The cost of producing milk, breed diversity, animal maintenance, *etc*., all have a big influence on the sustainability and profitability of the businesses involved. Global competition is heavily influenced by factors like as infrastructure and facilities, farm size, processing capacity, milk quality and cost of production (Ohlan, 2012). Increased demand for milk or prospects for the dairy industry's expansion has been facilitated by population growth, rising income, shifting eating habits and increased income flexibility for dairy products (Rajeshwaran *et al*., 2015).

CONCLUSION

Technological innovations, such as automated milking systems and precision agriculture, have reshaped dairy farming. These advancements enhance efficiency and mark a shift towards a more interconnected future. Genetic improvements have optimized cattle for better yield, disease resistance and resilience. Genomics research helps balance production with ethical considerations. Socio-economic challenges, like economic instability and unequal resource access, affect small-scale farmers. Market fluctuations and limited resources hinder growth for some. To ensure inclusive progress, the industry must address these issues. Environmental sustainability is a central concern, with intensive farming contributing to methane emissions and resource depletion. A shift toward sustainable practices is necessary to reduce the ecological footprint. The industry must meet growing demand while minimizing environmental impact. The future of dairy farming relies on a collective effort to balance technological progress, environmental sustainability and socio-economic challenges, ensuring a harmonious and sustainable future for all.

ACKNOWLEDGEMENT

Funding details

This research received no external funding.

Disclaimers

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Data availability

The data analysed/generated in the present study will be made available from corresponding author upon reasonable request.

Availability of data and materials

Not applicable.

Use of artificial intelligence

Not applicable.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

Abubakar, B.S.U.I. and Ismail, N. (2012). Anaerobic digestion of cow dung for biogas production. *ARPN Journal of Engineering and Applied Sciences*. **7(2):** 169-172.

Alshahrani, S.M. (2024). Knowledge, attitudes and barriers toward using complementary and alternative medicine among medical and nonmedical university students: A cross-sectional study from Saudi Arabia. *Current Topics in Nutraceutical Research.* **22(3):** 889-894. https://doi.org/10.37290/ctnr2641-452X.22:889-894.

Barker, T., Bashmakov, I., Bernstein, L., Bogner, J.E., Bosch, P.R., Dave, R. and Nabuurs, G.J. (2009). Contribution of working group III to the fourth assessment report of the IPCC: Technical summary. In Climate change 2007: Mitigation contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change, intergovernmental panel on climate change Cambridge University Press. pp. 27-93.

Berendt, F.J., Fröhlich, T., Bolbrinker, P., Boelhauve, M., Güngör, T., Habermann, F.A. and Arnold, G.J. (2009). Highly sensitive saturation labeling reveals changes in abundance of cell cycle associated proteins and redox enzyme variants during oocyte maturation *in vitro*. *Proteomics*. **9(3):** 550-564.

Bishop, P.L., Hively, W.D., Stedinger, J.R., Rafferty, M.R., Lojpersberger, J.L. and Bloomfield, J.A. (2005). Multivariate analysis of paired watershed data to evaluate agricultural best management practice effects on stream water phosphorus. *Journal of Environmental Quality*. **34(3):** 1087-1101.

Bloch, V., Levit, H. and Halachmi, I. (2019). Assessing the potential of photogrammetry to monitor feed intake of dairy cows. *Journal of Dairy Research*. **86(1):** 34-39.

Boogaard, B.K., Oosting, S.J., Bock, B.B. and Wiskerke, J.S.C. (2011). The sociocultural sustainability of livestock farming: An inquiry into social perceptions of dairy farming. *Animal*. **5(9):** 1458-1466.

Brito, L.F., Oliveira, H.R., Houlahan, K., Fonseca, P.A., Lam, S., Butty, A.M. and Schenkel, F.S. (2020). Genetic mechanisms underlying feed utilization and implementation of genomic selection for improved feed efficiency in dairy cattle. *Canadian Journal of Animal Science*. **100(4):** 587-604.

Britt, J.H., Cushman, R.A., Dechow, C.D., Dobson, H., Humblot, P., Hutjens, M.F. and Stevenson, J.S. (2018). Invited review: Learning from the future-A vision for dairy farms and cows in 2067. *Journal of Dairy Science*. **101(5):** 3722-3741.

Cahoon, L.B., Mikucki, J.A. and Mallin, M.A. (1999). Nitrogen and phosphorus imports to the cape fear and neuse river basins to support intensive livestock production. *Environmental Science and Technology*. **33(3):** 410-415.

Cardoso, C.S., Hötzel, M.J., Weary, D.M., Robbins, J.A. and von Keyserlingk, M.A. (2016). Imagining the ideal dairy farm. *Journal of Dairy Science*. **99(2):** 1663-1671. doi: 10.3168/jds.2015-9925.

Carvalho, A., O'Mahony, N., Krpalkova, L., Campbell, S., Walsh, J. and Doody, P. (2019). Farming on the Edge: Architectural Goals. In 2019 8th International Conference on Agro-Geoinformatics (Agro-Geoinformatics). IEEE. pp. 1-6.

Chizzotti, M.L., Machado, F.S., Valente, E.E.L., Pereira, L.G.R., Campos, M.M., Tomich, T.R. and Ribas, M.N. (2015). Validation of a system for monitoring individual feeding behavior and individual feed intake in dairy cattle. *Journal of Dairy Science*. **98(5):** 3438-3442.

Cho, O.H. (2024). An evaluation of various machine learning approaches for detecting leaf diseases in agriculture. *Legume Research*. **47(4):** 619-627. doi: 10.18805/LRF-787.

Danne, M. and Musshoff, O. (2017). Analysis of farmers' willingness to participate in pasture grazing programs: Results from a discrete choice experiment with German dairy farmers. *Journal of Dairy Science*. **100(9):** 7569-7580.

De Klein, C.A.M. and Eckard, R.J. (2008). Targeted technologies for nitrous oxide abatement from animal agriculture. *Australian Journal of Experimental Agriculture*. **48(2):** 14-20.

De Mauro, A., Greco, M. and Grimaldi, M. (2016). A formal definition of Big Data based on its essential features. *Library Review*. **65(3):** 122-135.

DeVries, T.J., Von Keyserlingk, M.A.G., Weary, D.M. and Beauchemin, K.A. (2003). Validation of a system for monitoring feeding behavior of dairy cows. *Journal of Dairy Science*. **86(11):** 3571-3574.

Dhanabalan, M. (2009). Productive efficiency of milk production in Tamil Nadu. *Indian Journal of Marketing*. **39(12):** 57-61.

Flint, A.P.F. and Woolliams, J.A. (2008). Precision animal breeding. *Philosophical Transactions of the Royal Society B: Biological Sciences*. **363(1491):** 573-590.

Foris, B., Zebunke, M., Langbein, J. and Melzer, N. (2019). Comprehensive analysis of affiliative and agonistic social networks in lactating dairy cattle groups. *Applied Animal Behaviour Science*. **210:** 60-67.

Ganesan, M. (2013). A study on the economic contribution of dairy farming in india. *Shanlax International Journal of Economics*. **1(3):** 49-58.

Garner, J.B., Douglas, M.L., Williams, S.R.O., Wales, W.J., Marett, L.C., Nguyen, T.T.T., Reich, C.M. and Hayes, B.J. (2016). Genomic selection improves heat tolerance in dairy cattle. *Scientific Reports*. **6(1):** 1-9.

García-Ruiz, A., Cole, J.B., VanRaden, P.M., Wiggans, G.R., Ruiz-López, F.J. and Van Tassell, C.P. (2016). Changes in genetic selection differentials and generation intervals in US Holstein dairy cattle as a result of genomic selection. *Proceedings of the National Academy of Sciences*. **113(28):** E3995-E4004.

Gastélum-Barrios, A., Soto-Zarazúa, G.M., Escamilla-García, A., Toledano-Ayala, M., Macías-Bobadilla, G. and Jauregui-Vazquez, D. (2020). Optical methods based on ultraviolet, visible and near-infrared spectra to estimate fat and protein in raw milk: A review. *Sensors*. **20(12):** 3356.

Gutierrez-Reinoso, M.A., Aponte, P.M. and Garcia-Herreros, M. (2021). Genomic analysis, progress and future perspectives in dairy cattle selection: A review. *Animals*. **11(3):** 599.

Heath, L.S., Smith, J.E., Skog, K.E., Nowak, D.J. and Woodall, C.W. (2011). Managed Forest carbon estimates for the US greenhouse gas inventory, 1990-2008. *Journal of Forestry*. **109(3):** 167-173.

Hoorman, J., Hone, T., Sudman Jr, T., Dirksen, T., Iles, J. and Islam, K.R. (2008). Agricultural impacts on lake and stream water quality in Grand Lake St. Marys, Western Ohio. *Water, Air and Soil Pollution*. **193(1-4):** 309-322.

Ibtisham, F., Zhang, L., Xiao, M., An, L., Ramzan, M.B., Nawab, A. and Xu, Y. (2017). Genomic selection and its application in animal breeding. *The Thai Journal of Veterinary Medicine*. **47(3):** 301-310.

Jackson, L.L., Keeney, D.R. and Gilbert, E.M. (2000). Swine manure management plans in north-central Iowa: Nutrient loading and policy implications. *Journal of Soil and Water Conservation*. **55(2):** 205-212.

Jaiswal, P., Chandravanshi, H. and Netam, A. (2018). Contribution of dairy farming in employment and household nutrition in India. *International Journal of Avian and Wildlife Biology*. **3(1):** 78-79.

James, E., Kleinman, P., Veith, T., Stedman, R. and Sharpley, A. (2007). Phosphorus contributions from pastured dairy cattle to streams of the Cannonsville Watershed, New York. *Journal of Soil and Water Conservation*. **62(1):** 40-47.

Johnson, O., Rebecca, O., Samson, O., Ajamu, O. (2018). Sustainable Management of cow dung from slaughter houses. *J. Eng. Technol.* **12(1):** 36-42.

Joshi, K.H., Mason, A., Shaw, A., Korostynska, O., Cullen, J.D. and Al-Shamma'a, A. (2015). Online monitoring of milk quality using electromagnetic wave sensors. In 2015 9th International Conference on Sensing Technology (ICST) IEEE. pp. 700-705.

Kant, K.K., Gopal Sankhala, G.S. and Kamta Prasad, K.P. (2015). Constraints Perceived by the Dairy Farmers in Adapting to Changing Climate in Western Dry Region of India. *Indian Journal of Dairy Science*. **68(4).**

Khatkar, M.S., Moser, G., Hayes, B.J. and Raadsma, H.W. (2012). Strategies and utility of imputed SNP genotypes for genomic analysis in dairy cattle. *BMC genomics*. **13:** 1-12.

Kim, S.Y. and AlZubi, A.A. (2024). Blockchain and artificial intelligence for ensuring the authenticity of organic legume products in supply chains. *Legume Research*. **47(7):** 1144-1150. doi: 10.18805/LRF-786.

Koike, T., Yamamoto, S., Furui, T., Miyazaki, C., Ishikawa, H. and Morishige, K.I. (2023). Evaluation of the relationship between equol production and the risk of locomotive syndrome in very elderly women. *International Journal of Probiotics and Prebiotics*. **18(1):** 7-13. https://doi.org/10.37290/ijpp2641-7197.18:7-13.

König, S. and May, K. (2019). Invited review: Phenotyping strategies and quantitative-genetic background of resistance, tolerance and resilience associated traits in dairy cattle. *Animal*. **13(5):** 897-908.

Leliveld, L.M. and Provolo, G. (2020). A review of welfare indicators of indoor-housed dairy cow as a basis for integrated automatic welfare assessment systems. *Animals*. **10(8):** 1430.

Lozada-Soto, E.A., Maltecca, C., Lu, D., Miller, S., Cole, J.B. and Tiezzi, F. (2021). Trends in genetic diversity and the effect of inbreeding in American Angus cattle under genomic selection. *Genetics Selection Evolution*. **53(1):** 1-15.

Luo, J. and Saggar, S. (2008). Nitrous oxide and methane emissions from a dairy farm stand-off pad. *Australian Journal of Experimental Agriculture*. **48(2):** 179-182.

Matthews, D., Kearney, J.F., Cromie, A.R., Hely, F.S. and Amer, P.R. (2019). Genetic benefits of genomic selection breeding programmes considering foreign sire contributions. *Genetics Selection Evolution*. **51(1):** 1-11.

Meena, P.C., Meena, P.C., Parewa, H.P., Choudhary, A. and Kumar, H. (2017). Problem and prospects of dairy industry in India. *Rashtriya Krishi*. **12(2):** 83-86.

Melzer, N., Foris, B. and Langbein, J. (2021). Validation of a real-time location system for zone assignment and neighbor detection in dairy cow groups. *Computers and Electronics in Agriculture*. **187:** 106280.

Min, P.K., Mito, K. and Kim, T.H. (2024). The evolving landscape of artificial intelligence applications in animal health. *Indian Journal of Animal Research*. **58(10):** 1793-1798. doi: 10.18805/IJAR.BF-1742.

Mondou, E., Dufort, I., Gohin, M., Fournier, E. and Sirard, M.A. (2012). Analysis of microRNAs and their precursors in bovine early embryonic development. *Molecular Human Reproduction*. **18(9):** 425-434.

Moran, J. (2005). Tropical dairy farming: feeding management for smallholder dairy farmers in the humid tropics. CSIRO Publishing.

Munir, M.T., Yu, W., Young, B.R., Wilson, D.I., Information, I. and Centre, C. (2015). The current status of process analytical technologies in the dairy industry. *Trends in Food Science and Technology*. **43(2):** 205-218.

Nguyen, T.T., Bowman, P.J., Haile-Mariam, M., Pryce, J.E. and Hayes, B.J. (2016). Genomic selection for tolerance to heat stress in Australian dairy cattle. *Journal of Dairy Science*. **99(4):** 2849-2862.

Nyokabi, S.N., de Boer, I J., Luning, P.A., Korir, L., Lindahl, J., Bett, B. and Oosting, S.J. (2021). Milk quality along dairy farming systems and associated value chains in Kenya: An analysis of composition, contamination and adulteration. *Food Control*. **119:** 107482.

Ohlan, R. (2012). Global competitiveness in dairy sector. *Available at SSRN 2797987*.

Oenema, O., Wrage, N., Velthof, G.L., van Groenigen, J.W., Dolfing, J. and Kuikman, P.J. (2005). Trends in global nitrous oxide emissions from animal production systems. *Nutrient Cycling in Agroecosystems*. **72:** 51-65.

Onzima, R.B. (2019). Genome-wide analysis of goat genetic diversity and production systems in Uganda (Doctoral dissertation, Wageningen University and Research).

Owens, L.B. and Shipitalo, M.J. (2006). Surface and subsurface phosphorus losses from fertilized pasture systems in Ohio. *Journal of Environmental Quality*. **35(4):** 1101-1109.

Patil, A.A.H., Jakatdar, E.G., Bhadreshwarmath, S.C., Kumbhar, V.R., Mitragotri, P.P., Deshmukh, B.B. and Mistry, R.D. (2021, July). Design of a low-cost system for determination of fat using IOT and ML. In *Journal of Physics: Conference Series*. IOP Publishing. **1969(1):** 012034

Poghossian, A., Geissler, H. and Schöning, M.J. (2019). Rapid methods and sensors for milk quality monitoring and spoilage detection. *Biosensors and Bioelectronics*. **140:** 111272.

Porto, S.M.C., Arcidiacono, C., Giummarra, A., Anguzza, U. and Cascone, G. (2014). Localisation and identification performances of a real-time location system based on ultra wide band technology for monitoring and tracking dairy cow behaviour in a semi-open free-stall barn. *Computers and Electronics in Agriculture*. **108:** 221-229.

Pryce, J.E., Wales, W.D., De Haas, Y., Veerkamp, R.F. and Hayes, B.J. (2014). Genomic selection for feed efficiency in dairy cattle. *Animal*. **8(1):** 1-10.

Rahman, M.A., Juyena, N.S., Shamsuddin, M. and Bhuiyan, M.M.U. (2021). Genomic tools and genetic improvement of crossbred friesian cattle. *Research in Agriculture, Livestock and Fisheries*. **8(1):** 89-107.

Rajeshwaran, S., Gopal, N. and Niharika, G. (2015, August). Determinants of milk price in India: An exploratory study. In Proceeding 10th Annual International Conference on Public Policy and Management.

Rotz, C.A., Sharpley, A.N., Satter, L.D., Gburek, W.J. and Sanderson, M.A. (2002). Production and feeding strategies for phosphorus management on dairy farms. *Journal of Dairy Science*. **85(11):** 3142-3153.

Rotz, C.A., Taube, F., Russelle, M.P., Oenema, J., Sanderson, M.A. and Wachendorf, M. (2005). Whole farm perspectives of nutrient flows in grassland agriculture. *Crop Science*. **45(6):** 2139-2159.

Saravanan, S., Kavinkumar, M., Kokul, N.S., Krishna, N.S. and Nitheeshkumar, V.I. (2021, May). Smart milk quality analysis and grading using IoT. In 2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS) IEEE. pp. 378-383.

Schils, R.L.M., Van Groenigen, J.W., Velthof, G.L. and Kuikman, P.J. (2008). Nitrous oxide emissions from multiple combined applications of fertiliser and cattle slurry to grassland. *Plant and Soil*. **310:** 89-101.

Showers, W.J., Genna, B., McDade, T., Bolich, R. and Fountain, J.C. (2008). Nitrate contamination in groundwater on an urbanized dairy farm. *Environmental Science and Technology*. **42(13):** 4683-4688.

Schröder, J.J., Aarts, H.F.M., Van Middelkoop, J.C., Schils, R.L.M., Velthof, G.L., Fraters, B. and Willems, W.J. (2007). Permissible manure and fertilizer use in dairy farming systems on sandy soils in The Netherlands to comply with the Nitrates Directive target. *European Journal of Agronomy*. **27(1):** 102-114.

Singh, M. and Joshi, A.S. (2008). Economic analysis of crop production and dairy farming on marginal and small farms in Punjab. *Agricultural Economics Research Review*. **21(347-2016-16692):** 251-257.

Soder, K.J. and Rotz, C.A. (2001). Economic and environmental impact of four levels of concentrate supplementation in grazing dairy herds. *Journal of Dairy Science*. **84(11):** 2560-2572.

Soupir, M.L., Mostaghimi, S. and Yagow, E.R. (2006). Nutrient transport from livestock manure applied to pastureland using phosphorus based management strategies. *Journal of Environmental Quality*. **35(4):** 1269-1278.

Steinfeld, H. and Wassenaar, T. (2007). The role of livestock production in carbon and nitrogen cycles. *Annu. Rev. Environ. Resour.* **32:** 271-294.

Toth, J.D., Dou, Z., Ferguson, J.D., Galligan, D.T. and Ramberg Jr, C.F. (2006). Nitrogen vs. phosphorus based dairy manure applications to field crops: Nitrate and phosphorus leaching and soil phosphorus accumulation. *Journal of Environmental Quality*. **35(6):** 2302-2312.

Van der Meer, H.G. (2008). Optimising manure management for GHG outcomes. *Australian Journal of Experimental Agriculture*. **48(2):** 38-45.

Veissier, I., Mialon, M.M. and Sloth, K.H. (2017). Early modification of the circadian organization of cow activity in relation to disease or estrus. *Journal of Dairy Science*. **100(5):** 3969-3974.

Vukasinovic, N., Bacciu, N., Przybyla, C.A., Boddhireddy, P. and DeNise, S.K. (2017). Development of genetic and genomic evaluation for wellness traits in US Holstein cows. *Journal of Dairy Science*. **100(1):** 428-438.

Wallén, S.E., Lillehammer, M. and Meuwissen, T.H.E. (2017). Strategies for implementing genomic selection for feed efficiency in dairy cattle breeding schemes. *Journal of Dairy Science*. **100(8):** 6327-6336.

Walsh, S.W., Mehta, J.P., McGettigan, P.A., Browne, J.A., Forde, N., Alibrahim, R.M. and Evans, A.C. (2012). Effect of the metabolic environment at key stages of follicle development in cattle: Focus on steroid biosynthesis. *Physiological Genomics*. **44(9):** 504-517.

Wiggans, G.R., Cole, J.B., Hubbard, S.M. and Sonstegard, T.S. (2017). Genomic Selection in Dairy Cattle. *Annu. Rev. Anim. Biosci.* **5(1):** 309-327.

Willaarts, B., Pardo, I. and Mora, G.D.L. (2013). Urbanization, socio-economic changes and population growth in Brazil: Dietary shifts and environmental implications. Proceedings of XXVII IUSSP International Population Conference. pp. 1-18.

Wolfert, S., Ge, L., Verdouw, C. and Bogaardt, M.J. (2017). Big data in smart farming-A review. *Agricultural Systems*. **153:** 69-80.

Wolfert, S., Goense, D. and Sørensen, C.A.G. (2014). A Future Internet Collaboration Platform for Safe and Healthy Food From Farm to Fork. In 2014 Annual SRII Global Conference IEEE. pp. 266-273.

Wurtz, K., Camerlink, I., D'Eath, R.B., Fernández, A.P., Norton, T., Steibel, J. and Siegford, J. (2019). Recording behaviour of indoor-housed farm animals automatically using machine vision technology: A systematic review. *PloS one*. **14(12):** e0226669.

Zamora-Izquierdo, M.A., Santa, J., Martínez, J.A., Martínez, V. and Skarmeta, A.F. (2019). Smart farming Iot platform based on edge and cloud computing. *Biosystems Engineering*. **177:** 4-17.