



Revolutionizing India's Dairy Industry: The Role of Artificial Intelligence in Sustainable and Scalable Milk Production

Rinmuanpuii Ralte¹, Maninder Singh², Pallvi Slathia³, Vipan Kumar³
K. Lalawmpuii⁴, Satuti Sharma⁵, Lalrinkima⁶, Harish Kumar Verma⁷

10.18805/ajdfr.DR-2355

ABSTRACT

The dairy industry serves as a cornerstone of India's agricultural economy, contributing significantly to rural livelihoods, nutritional security and overall economic development. The sector is deeply integrated into the rural economy, with millions of landless, marginal and small-scale dairy farmers who possess approximately 70.00 to 75.00 per cent of the dairy animals forming its backbone. However, several challenges including low productivity levels, climate-induced risks and inefficient resource management necessitate modern, innovative solutions. The convergence of traditional dairy farming with cutting-edge artificial intelligence (AI) technologies is revolutionizing the sector, unlocking new avenues for enhanced productivity, efficiency and sustainability. AI-driven advancements such as automated milking systems, real-time animal health monitoring and smart supply chain optimization are transforming dairy operations by increasing milk yields, improving cattle welfare and streamlining logistics. Additionally, AI fosters socio-economic growth by empowering small-scale farmers and rural communities through accessible technologies that reduce costs, optimize feeding strategies and support better herd management. However, widespread AI adoption requires addressing key hurdles including high implementation costs, technological accessibility, data privacy risks and ethical concerns regarding environmental sustainability. This article explores the evolving landscape of AI integration in Indian dairy farming, highlighting its transformative impact while critically assessing the challenges and opportunities that lie ahead for creating a sustainable, technologically advanced dairy sector.

Key words: Artificial Intelligence, Cattle health monitoring, Dairy supply chain monitoring, Machine learning, Precision dairy farming, Sustainable milk production.

India's dairy industry stands as a cornerstone of the nation's agricultural economy, contributing significantly to rural livelihoods, nutritional security and overall economic development. As the largest milk producer in the world, India produced 239.30 million tons (MT) of milk, accounting for approximately 25.00 per cent of global milk production in 2023-24 (BAHS, 2024; Dairy dimension, 2025). The sector is deeply integrated into the rural economy, with millions of small-scale dairy farmers forming its backbone (Indian dairyman, 2024).

In 2024, the Indian dairy market was valued at INR 18,975 billion and is projected to grow at a robust 12.35 per cent compound annual growth rate (CAGR), reaching INR 57,001.81 billion by 2033 (IMARC Report, 2025). In India, approximately 37.00 per cent of milk produced is either consumed at the producer level or sold to non-producers in rural areas; the remaining 63.00 per cent is available for sale to organized and unorganized players (DAHD, 2024).

The demand for dairy products in India is driven by multiple factors: population growth, urbanization, increasing per capita income, advancements in cold chain infrastructure and the rise of organized retail and e-commerce platforms (Williams, 2024). The dairy sector plays a vital role in India's GDP, contributing 5.00 per cent to the agricultural GDP and ensuring food security for the population (DAHD, 2024). With per capita milk availability

¹Department of Veterinary Clinical Diagnostics, Khalsa College of Veterinary and Animal Sciences, Amritsar-143 001, Punjab, India.

²Department of Veterinary and Animal Husbandry Education Extension, Khalsa College of Veterinary and Animal Sciences, Amritsar-143 001, Punjab, India.

³Department of Veterinary Microbiology, Khalsa College of Veterinary and Animal Sciences, Amritsar-143 001, Punjab, India.

⁴Department of Veterinary Parasitology, Khalsa College of Veterinary and Animal Sciences, Amritsar-143 001, Punjab, India.

⁵Department of Veterinary Pathology, Khalsa College of Veterinary and Animal Sciences, Amritsar-143 001, Punjab, India.

⁶Department of Veterinary Pathology, Institute of Veterinary Sciences and Animal Husbandry, Siksha 'O' Anusandhan (Deemed University), Bhubaneswar-751 001, Odisha.

⁷Khalsa College of Veterinary and Animal Sciences, Amritsar-143 001, Punjab, India.

Corresponding Author: Rinmuanpuii Ralte, Department of Veterinary Clinical Diagnostics, Khalsa College of Veterinary and Animal Sciences, Amritsar-143 001, Punjab, India.
Email: puiralte@yahoo.co.in

How to cite this article: Ralte, R., Singh, M., Slathia, P., Kumar, V., Lalawmpuii, K., Sharma, S., Lalrinkima, and Verma, H.K. (2026). Revolutionizing India's Dairy Industry: The Role of Artificial Intelligence in Sustainable and Scalable Milk Production. *Asian Journal of Dairy and Food Research*. 1-9. doi: 10.18805/ajdfr.DR-2355.

Submitted: 26-05-2025 **Accepted:** 15-01-2026 **Online:** 31-01-2026

at 471 g per day, the industry not only meets domestic demand but also positions India as a key player in the global dairy market (CEIC database, 2024; DADH, 2024). Despite being the largest milk producer globally, the dairy industry faces several systemic challenges that hinder its growth and sustainability. Low productivity remains a pressing issue as indigenous breeds of dairy animals yield significantly less milk compared to international standards, largely due to inadequate nutrition, poor genetic potential and limited veterinary care (Banerjee, 2023; Roy and Chaturvedani, 2024). Operational inefficiencies further exacerbate the situation with a predominantly unorganized sector where small-scale farmers lack access to modern infrastructure, adequate knowledge and empowerment to seek government services or take advantage of market opportunities. Insufficient cold storage and inefficient supply chains also lead to significant post-production losses and price volatility (NDDB, 2023).

Sustainability presents another critical concern, as environmental issues such as scarcity of fodder and water, climate change and methane emissions from buffaloes - which contribute nearly 45.00 per cent of milk production - pose significant threats (NDDB, 2023; Wijerathna and Pathirana, 2022). Unsustainable practices including overgrazing and inadequate waste management further jeopardize long-term viability (Banerjee, 2023). Addressing these challenges requires a multi-pronged approach including genetic improvement programs, capacity development, infrastructure development (particularly cold chains), adoption of eco-friendly practices and enhanced policy support to empower small-scale farmers (Basaragi and Kadam, 2024; NDDB, 2024). These efforts are crucial for ensuring sustainable growth and securing the sector's contribution to rural livelihoods and the Indian economy.

India's dairy industry is now poised for a remarkable transformation, fuelled by the ambitious National Digital Livestock Mission as detailed in the Indian Dairy Association publication. This initiative leverages artificial intelligence (AI) to revolutionize traditional practices, aiming to enhance animal productivity, ensure food security and promote sustainable growth. By harnessing the power of data analytics and cutting-edge technologies, AI opens up new horizons for dairy farmers unlocking unprecedented efficiencies, optimizing operations and paving the way for a brighter, more resilient future. As the industry embraces this technological leap, it positions itself as a global leader in sustainable agriculture (Joshi, 2023).

Artificial Intelligence is emerging as a transformative force across all sectors in India, including the dairy industry, addressing critical challenges in productivity, efficiency and sustainability. By leveraging advanced technologies such as machine learning (ML), deep learning (DL), predictive analytics and IoT-enabled devices, AI empowers farmers with real-time insights into cattle health, milk quality and feed optimization (Oliviera *et al.*, 2021; Fuentes *et al.*, 2022; Shine and Murphy, 2022; Bello and Moradeyo, 2023; Wang *et al.*, 2025; Tamanna, 2025).

According to dollons food products (2024) and dairy dimension (2025), AI has already shown significant promise in improving efficiency and sustainability in dairy farming. For instance, AI-powered sensors and smart collars facilitate continuous monitoring of cattle behavior, enabling early detection of estrus and signs of diseases while optimizing feeding strategies, significantly reducing health expenses and improving milk yield (Neethirajan, 2020; Kumar and Singh, 2020). Additionally, AI enhances supply chain efficiency by optimizing inventory management, distribution routes and demand forecasting, thereby minimizing wastage and transportation costs (NDDB, 2024; Dollons, 2024). These innovations not only boost profitability but also promote eco-friendly practices, making the dairy sector more sustainable and resilient. As India continues to embrace AI-driven solutions, the dairy industry is poised for a technological revolution that will strengthen its contribution to the economy and rural livelihoods (FAS, 2024).

Current status of dairy farming in india

India is the largest milk producer globally with total milk production of approximately 239.30 million tons, contributing around 25.00 per cent to global milk production. Small-scale farmers play a pivotal role in this achievement, contributing nearly 60.00 per cent of total milk production (FAS, 2024; IMARC, 2025). These farmers, typically owning 2-5 cattle, depend on traditional methods and cooperative networks for milk collection and distribution. Although India's per capita milk availability underscores the sector's vital role in nutritional security, numerous challenges hinder the growth and sustainability of conventional dairy practices. Small-scale farmers often face low productivity due to the genetic limitations of indigenous breeds, inadequate nutrition, limited access to veterinary care and minimal investment in farm knowledge. Additionally, resource constraints such as outdated infrastructure, poor cold chain facilities and inefficient supply chains lead to significant post-harvest losses and market instability.

Another critical issue affecting milk quality is adulteration with a wide variety of common adulterants such as water, carbohydrate solutions, detergents, neutralizers and synthetic milk substitutes like melamine, which pose widespread and significant health risks for Indian consumers (Tiwari *et al.*, 2013; Reddy *et al.*, 2017). To address this issue, current guidelines include adoption of rapid enzyme-based or strip testing kits to ensure authenticity of milk at the farm level and during transportation, strengthening regulatory oversight, increasing awareness among farmers and consumers and implementing strict penal actions against adulterators (FSSAI, 2021; DADH, 2024). AI-mediated control plays a growing role in addressing milk adulteration issues by enhancing the accuracy, speed and efficiency of detecting adulterants, ensuring safer milk quality for consumers (Lal and Singh, 2021; Sharma and Kumar, 2022; DAHD, 2024).

Environmental issues like fodder and water shortages, methane emissions from buffaloes and climate change

further threaten the sector's sustainability. To combat these challenges, innovative technologies are being introduced. IoT-enabled devices and smart sensors now monitor cattle health, optimize feeding and facilitate early disease detection (Yu *et al.*, 2024). Automated milking systems enhance operational efficiency and reduce reliance on manual labour (Lee *et al.*, 2020). Blockchain technology ensures transparency and traceability, maintaining milk quality across the supply chain (Alshehri, 2023). Ultra-high temperature (UHT) processing extends milk shelf life, reducing waste, while GPS-enabled chilling units and refined logistics help minimize spoilage and improve distribution efficiency (Pathak and Rathore, 2023a; FAS, 2024).

Role of artificial intelligence in dairy farming

AI is paving the way for a smarter, more resilient dairy industry, ensuring economic growth and environmental sustainability (Kumar and Singh, 2020; Morrone *et al.*, 2022; Kumar and Patel, 2023). It encompasses a range of transformative technologies that are reshaping industries, including dairy farming. One notable initiative leveraging these technologies is the Dairy Brain Project by the University of Wisconsin-Madison. This project aims to create a "Virtual Dairy Farm Brain" by integrating real-time data streams from dairy farms into a centralized system. The Dairy Brain uses advanced data analytics and IoT-enabled devices to monitor cow health, feed efficiency, milk production and environmental factors. By providing predictive insights and decision-making tools, the project helps farmers optimize operations, reduce costs and enhance sustainability (Patel and Sharma, 2022).

Benefits of AI in improving productivity, reducing costs and enhancing sustainability

Integration of AI into farming has transformed operations, delivering remarkable advancements in management efficiency, animal health, economic performance and sustainability (Zhang *et al.*, 2022; Li *et al.*, 2023a). By harnessing AI technologies, farms can address long-standing challenges and embrace innovative solutions for growth (Choyal, 2023; Min *et al.*, 2024; Jeevanandam, 2024; Cabrera, 2025).

Improved farm management

AI revolutionizes dairy management by optimizing feed efficiency, improving reproductive outcomes (Li *et al.*, 2023b) and enhancing animal health monitoring. AI systems analyze data on feed consumption and milk output to develop cost-effective feeding strategies that maintain both animal health and milk quality (Barrientos-Blanco *et al.*, 2020; Chelotti *et al.*, 2023; Pan *et al.*, 2023a). Predictive analytics forecast milk yields with high accuracy and refine breeding protocols, ensuring maximum productivity and profitability (Lee *et al.*, 2020; Zhang *et al.*, 2024). Moreover, continuous health monitoring using AI enables early detection of illnesses or stress, empowering farm

managers to intervene promptly and mitigate potential losses (Sharma and Rajput, 2024). This proactive approach promotes animal welfare and secures consistent production (Fadul-Pachero *et al.*, 2021; Shine and Murphy, 2022; Zhang *et al.*, 2022).

Enhanced operational efficiency

AI streamlines farm operations by automating data-intensive tasks, reducing the workload on farm staff and enabling more informed decisions (Sharma *et al.*, 2020; Pan *et al.*, 2023b; Aharwal *et al.*, 2023). By managing feed timing and quantities, AI ensures optimal milk production per feed unit while minimizing waste (Tassinari *et al.*, 2021; Chelotti *et al.*, 2023; King *et al.*, 2024). Barrientos-Blanco *et al.* (2020) demonstrated that optimizing diet accuracy through AI reduced feed costs by \$31 per cow annually and lowered nitrogen excretion by 5.50 kg per cow per year. These improvements, achieved through precise grouping and tailored diets, demonstrate both economic and environmental gains facilitated by data-driven management practices (Barrientos-Blanco *et al.*, 2020; Pathak and Rathore, 2023b).

Proactive animal health monitoring

AI-powered monitoring systems identify subtle changes in animal behavior or physiology that may indicate health issues by analyzing integrated farm data in real-time (Smith and Lee, 2022). Machine learning algorithms predict diseases like mastitis with up to 72.00 per cent accuracy (Fadul-Pachero *et al.*, 2021), allowing timely medical intervention, preventing minor ailments from escalating and reducing veterinary costs (Johnson *et al.*, 2021). Integrated AI-wearable sensors facilitate consistent health monitoring, support animal welfare, ensure high-quality milk production and mitigate the economic impacts of disease outbreaks (Wang and Zhang, 2021; Ding *et al.*, 2025).

Economic advantages

AI solutions significantly enhance farm profitability by improving efficiency and herd health while reducing costs (Kumar and Patel, 2023). Accurate predictions of breeding cycles and lactation peaks optimize productivity, boosting financial returns (Zhao *et al.*, 2022; Pan *et al.*, 2023a). For example, Li *et al.* (2023b) found that minor adjustments in reproductive management based on AI-driven insights could increase profitability by up to \$30 per cow annually (Martinez *et al.*, 2023). These small yet impactful changes demonstrate the financial value of data-informed strategies in maintaining a competitive edge in fluctuating market conditions (Garcia *et al.*, 2021).

Sustainability and environmental impact

AI fosters sustainability in dairy farming by promoting efficient resource use, minimizing waste and reducing environmental footprints (Johnson *et al.*, 2021). AI systems enable precise water and energy management, lower methane emissions through optimized feeding practices and support waste recycling (Altshuler *et al.*, 2025). Walker

et al. (2023) showcased how AI-enabled practices align with environmental regulations while appealing to eco-conscious consumers. Adopting these technologies positions farms to meet sustainability standards and enhance their competitiveness in an increasingly demanding market.

Case studies and success stories in ai implementation: indian scenario

The press Information bureau underscores the importance of programs initiated by the Government of India, such as the Rashtriya Gokul Mission, which focuses on development and conservation of indigenous breeds and genetic upgradation of bovine populations to support rural farmers and advance tech-driven solutions (NDDDB, 2024). The following case studies highlight the transformative impact of AI on Indian dairy farms, showcasing its potential to modernize operations, enhance productivity and ensure sustainable growth.

Amul cooperative: AI-driven quality control and supply chain management

One notable example of AI integration in Indian dairy farming is the Amul Cooperative, which has embraced AI technologies to optimize production, quality control and supply chain management. Amul uses predictive analytics to forecast milk production volumes and manage inventory levels effectively, reducing waste and ensuring consistent product availability. Additionally, AI-powered computer vision systems monitor milk quality during processing, detecting anomalies in texture and consistency to maintain high standards (Sharma and Kumar, 2022; AI and AMUL, 2024). This integration has enabled Amul to maintain its position as India's leading dairy cooperative while ensuring product quality and operational efficiency.

Precision agriculture in rajasthan: Empowering small-scale farmers

Another success story is the adoption of AI-driven precision agriculture by small-scale farmers in Rajasthan. AI tools analyze data from IoT sensors to optimize feed management and reproductive performance, resulting in increased milk yields and improved herd health (Pathak and Rathore, 2023b). These technologies have empowered farmers to make data-driven decisions, enhancing efficiency and productivity across the dairy value chain. The success in Rajasthan demonstrates that AI technologies can be effectively scaled for small-scale operations, providing a model for other regions.

Bharat pashudhan: National digital infrastructure for livestock management

The cloud-based platform 'Bharat Pashudhan', launched by NDDDB in collaboration with DADH, serves as a farmer-centric, technology-driven digital infrastructure designed to enhance productivity and health management in India's animal breeding, nutrition and health sectors. As of March

2024, the platform covers 26 states and 8 union territories, significantly expanding its reach.

A pilot digital livestock census conducted in December 2023 using the Bharat Pashudhan App revealed that 95.50 per cent of the total animal population in Dehradun district had been tagged and verified, with a 100.00 per cent registration rate for bovines. This demonstrated the app's capability in improving transparency and accountability in livestock management, facilitating effective resource allocation for stray animal management and enhancing animal welfare (Choudhary and Singh, 2024). The success of Bharat Pashudhan underscores its potential to revolutionize India's livestock sector, ensuring data-driven decision-making and fostering sustainable agricultural practices (NDDDB, 2023; NDDDB, 2024).

Other national initiatives

Additional initiatives includes the national animal disease reporting system (NADRS) implemented by the department of fisheries, animal husbandry and dairying through the National Informatics Centre, which enables veterinary authorities to closely monitor, control and eradicate animal diseases. The Dairy Information System Kiosk (DISK), developed by IIM Ahmedabad, is a portal that provides information and services in nine Indian languages across six domains including Livestock Development. The system is executed by the Centre for Development of Advanced Computing (C-DAC), Hyderabad (Thakur *et al.*, 2023).

Insights into scaling Up production and improving efficiency

AI has proven instrumental in helping Indian farmers scale up production and improve operational efficiency. For instance, robotic milking systems driven by AI provide stress-free milking experiences for cows, leading to higher milk yields and better herd health. These systems automate labor-intensive tasks, allowing farmers to focus on strategic decision-making and reducing dependency on manual labor (Kumar and Sinha, 2022; Pathak and Rathore, 2023a).

AI-powered predictive modeling has also optimized inventory management and distribution routes, minimizing transportation costs and wastage (Patel and Singh, 2023). Farmers using AI-driven health monitoring systems have reported significant reductions in veterinary expenses, as early detection of diseases enables timely interventions (Ali AlZubi, 2023; Sharma and Rajput, 2024). These advancements not only boost profitability but also promote sustainability by reducing the environmental footprint of dairy farming (Dollons, 2024; Espinoza-Sandoval *et al.*, 2024; Cabrera, 2025; Das and Chatterjee, 2025).

Challenges and barriers to AI adoption in dairy farming

High implementation costs

AI systems require substantial investments in hardware, software and ongoing maintenance, which are often

financially prohibitive for small and medium-scale farms operating on narrow profit margins (Verma and Kumar, 2021). The initial capital requirements for sensors, automated systems and data infrastructure can be overwhelming for farmers with limited access to credit or capital.

Lack of awareness and resistance to change

Many farmers, particularly those managing small-scale operations, are unfamiliar with AI technologies or perceive them as complex and intimidating (Watson and Rahmani, 2025). Fear of disruption to established practices and uncertainty about returns on investment create resistance to adoption. This technological gap is particularly pronounced in rural areas where exposure to advanced technologies is limited.

Data privacy and security concerns

Farmers may worry about ownership and potential misuse of sensitive farm data collected by AI systems, especially when managed by third-party platforms (Mishra and Patel, 2023). Questions about who owns the data, how it will be used and whether it could be shared with competitors or government agencies create hesitation. Clear data governance frameworks are critical to building trust (Dwivedi *et al.*, 2023).

Infrastructure limitations

Inadequate digital infrastructure, particularly unreliable internet connectivity in rural areas, poses significant barriers to AI implementation. Without robust connectivity, real-time data transmission and cloud-based analytics become impractical, limiting the effectiveness of AI solutions.

Suggestions for overcoming barriers

Government support and policy interventions

Financial incentives such as subsidies, grants, or cost-sharing programs can help reduce the burden of high implementation costs (Rao and Sharma, 2020). Policymakers should support research and development tailored to small-scale farming needs, creating specialized funding mechanisms for AI adoption in agriculture (Hassoun *et al.*, 2023). Tax incentives for technology purchases and low-interest loan programs can further facilitate adoption.

Industry-academia collaboration

Industry-academia partnerships play a vital role in advancing AI adoption in dairy farming by developing innovative and cost-effective hardware and software solutions tailored to the unique needs of both small and large farms (Reddy and Rao, 2020). This partnership facilitates testing and validation of AI systems within real farming environments, ensuring their practicality, robustness and suitability. Additionally, fostering strong public-private sector collaborations can accelerate the commercialization and wider deployment of AI technologies, making them more accessible and adaptable to the diversity of Indian dairy farms (Kumar and Singh, 2021).

Comprehensive training and education programs

Workshops, training sessions and extension services can familiarize farmers with AI systems, demonstrating practical benefits and reducing resistance to technology adoption (Kumar and Singh, 2021; Zhang *et al.*, 2022). Training programs should be designed in local languages and contextualized to regional farming practices. Demonstration farms and peer learning networks can help farmers see tangible benefits before making investment decisions.

Establishing robust data governance frameworks

Transparent policies ensuring data ownership and privacy can build trust in AI systems. Collaboration with third-party platforms must focus on ethical data handling and user control (Cue *et al.*, 2021; Mishra and Sharma, 2023). Clear regulations should define data rights, establish consent mechanisms and create accountability for data breaches. Farmers should have control over their data with options to opt-in or opt-out of data-sharing arrangements.

Infrastructure development initiatives

Investments in reliable internet access and compatible digital frameworks are essential for seamless AI integration, especially in rural areas (Das and Chatterjee, 2024; Madupati, 2025). Government and private sector partnerships should prioritize expanding broadband infrastructure to agricultural regions. Solar-powered connectivity solutions and offline AI capabilities can bridge gaps in areas with limited infrastructure.

Scaling AI for small farms

AI solutions need to be specifically tailored for small-scale farms to ensure accessibility and adaptability. Financial and technical resources must be allocated to facilitate scalability for diverse farming operations (Patel and Sharma, 2022). Modular AI systems that can be implemented incrementally, starting with basic functionalities and expanding over time, can make adoption more feasible for resource-constrained farmers.

Future prospects

The future of AI in the dairy industry is poised for significant advancements, with emerging technologies expected to enhance efficiency, productivity and sustainability. AI-driven predictive analytics, robotic milking systems and precision agriculture tools will advance further, enabling farmers to optimize milk yields, monitor animal health in real-time, detect diseases early, reduce losses and streamline supply chain operations (Reddy and Patel, 2021; Sharma and Kumar, 2022).

Empowering Small-scale farmers and rural communities

The integration of AI within India's dairy industry holds immense potential, particularly for small-scale farmers and rural communities, offering solutions to longstanding challenges while enhancing both productivity and sustainability (Choyal, 2023). AI-powered predictive analytics help farmers make informed decisions regarding

breeding cycles, milk production forecasting and resource management, ensuring better financial stability (Sunil and Rao, 2022).

For rural communities, AI adoption can bridge connectivity gaps by providing real-time insights through mobile applications and smart devices, enabling farmers to manage their operations more efficiently and effectively even in remote areas (Das and Singh, 2023; Jeevanandam, 2024). Government initiatives and private-sector investments in AI-driven dairy solutions and innovations are expected to accelerate this transition, making advanced technologies more accessible, affordable and scalable (CEDSI, 2024).

Furthermore, AI can foster environmental sustainability by optimizing water usage, reducing methane emissions and promoting eco-friendly dairy farming practices, thus ensuring the long-term viability of small-scale farms (Choyal, 2023; Chatterjee and Mukherjee, 2024).

Vision for a sustainable and technologically advanced industry

The vision for a sustainable and technologically advanced dairy industry in India revolves around integrating cutting-edge solutions to enhance productivity, efficiency and ecological balance. Initiatives like White Revolution 2.0 emphasize shifting the focus from merely increasing milk volume to improving quality, sustainability and farmer prosperity (Jain and Verma, 2023; Panda, 2025). By integrating AI with blockchain and IoT technologies, the sector can achieve greater transparency, traceability and efficiency, paving the way for a more sustainable future (Sunil and Rao, 2022; CEDSI, 2024).

Overcoming barriers such as high costs, infrastructure limitations and limited digital literacy will enable AI to empower small-scale farmers with data-driven solutions, fostering economic resilience and improving livelihoods across rural India (Jain and Verma, 2023).

The National Programme for Dairy Development (NPDD), supported by a ₹ 2,790 crore investment, aims to strengthen infrastructure, expand dairy cooperatives and improve rural livelihoods (Businessworld, 2025). Concurrently, innovations such as AI-enabled genetic improvement, IoT-based tracking systems and climate-resilient feed solutions are being introduced to reduce environmental impacts and increase milk yield (Sunil and Rao, 2022).

By harnessing these technological advancements, India can create a resilient, transparent and eco-friendly dairy industry that ensures food security, empowers small-scale farmers and aligns with global sustainability goals. The convergence of policy support, technological innovation and stakeholder collaboration will be critical in realizing this vision.

CONCLUSION

The integration of artificial intelligence (AI) is reshaping the dairy sector industry in India offering innovative

solutions for enhanced productivity, strengthening animal health management and improving supply chain efficiency, at the same time promoting environmental sustainability, from reducing methane emissions to optimizing water usage and waste management. Despite this transformative potential, challenges such as high implementation costs, farmer resistance, data privacy concerns, and infrastructure limitations must be addressed for AI to achieve its full impact. With strategic investments and supportive governance, affordable and scalable AI solutions tailored to diverse farm structures can be developed by industry-academia collaboration. Farmers, in turn, must embrace digital transformation, leveraging AI tools to optimize operations, reduce losses, and improve economic resilience.

Conflict of interest

The authors declare that there is no conflict of interests to disclose regarding this review article.

REFERENCES

- Aharwal, B., Roy, B., Meshram, S. and Yadav, A. (2023). Worth of artificial intelligence in the epoch of modern livestock farming: A review. *Agricultural Science Digest-A Research Journal*. **43(1)**: 1-9. doi: 10.18805/ag.D-5355.
- AI and Anand Milk Union Limited (2024). How Amul is transforming dairy production with cutting edge AI technologies. August 6, 2024. <https://www.cash-platform.com/how-amul-is-transforming-dairy-production-with-cutting-edge-ai-technologies/> (Accessed on May 2025).
- Ali AlZubi, A. (2023). Artificial Intelligence and its application in the prediction and diagnosis of animal diseases: A review. *Indian Journal of Animal Research*. **57(10)**: 1265-1271. doi: 10.18805/IJAR.BF-1684.
- Alshehri, M. (2023). Blockchain-assisted internet of things framework in smart livestock farming. *Internet of Things*. **22**: 100739.
- Altshuler, Y., Chebach, TC., Cohen, S. and Gatica, J. (2025). AI-driven precision agriculture for enteric methane mitigation: Cross-farm validation with an essential oil-based feed additive. *Frontiers in Sustainable Food Systems*. **9**: 1548223. doi: 10.3389/fsufs.2025.1548223.
- Banerjee, A. (2023). Dairying systems in India. <https://www.fao.org/4/T3080T/t3080T07.html> (Accessed on April, 2025).
- Barrientos-Blanco, JA., White, H., Shaver, RD. and Cabrera, VE. (2020). Improving nutritional accuracy and economics through multiple ration grouping strategy. *Journal of Dairy Science*. **103(4)**: 3774-3785. doi: 10.3168/jds.2019-17608.
- Basaragi, A. and Kadam, RN. (2024). Problems and prospects of dairy farming in India: An analysis of Karnataka state. *International Journal of Creative Research Thoughts*. **12(11)**: c75-c78.
- Basic Animal Husbandry Statistics (2024). Department of Animal Husbandry and Dairying, Ministry of Fishery, Animal Husbandry and Dairying, Government of India.
- Bello, RW. and Moradeyo, OM. (2023). Features-based individual cattle instance identification method using hybrid deep learning models for sustainable livestock management. *World Science News*. **180**: 119-131.

- Business World (2025). Govt enhances dairy development program with 2790 crores boost. March 20, 2025. <https://www.businessworld.in/article/govt-enhances-dairy-development-programme-with-rs-2790-crore-boost-551161>.
- Cabrera, VE. (2025). Artificial Intelligence applied to dairy science: Insights from the dairy brain initiative. *Animal Frontiers*. **14(6)**: 60-63. doi: 10.1093/af/vfae040.
- CEDSI (2024). Dairy technologies for growth of Indian Agriculture: A tech-driven transformation through AI, Machine learning and Block chain. <https://www.cedsi.in/blog/uncategorized/dairy-technologies-for-the-growth-of-indian-agriculture-a-tech-driven-transformation-through-ai-machine-learning-and-block-chain/>.
- CEIC Economic database (2024). India Livestock Production: Milk per capita availability 1951-2024, DADH, Govt. of India. <https://www.ceicdata.com/en/india/livestock-production-per-capita-availability/livestock-production-milk-per-capita-availability>.
- Chatterjee, P. and Mukherjee, S. (2024). Artificial Intelligence and environmental sustainability in Indian dairy sector. *Environmental Innovation and Societal Transition*. **16**: 100196. doi: 10.1016/j.iest.2024.100196.
- Chelotti, J., Martinez-Rau, L., Ferrero, M., Vignolo, L., Galli, J. and Planisich, A. (2023). Livestock feeding behaviour: A tutorial review on automated techniques for ruminant monitoring. arXiv Preprint arXiv: 2312.09259.
- Choudhary, V. and Singh, P. (2024). Digital transformation in Indian Livestock Sector: The role of AI and Data platforms. *Indian Journal of Agricultural Sciences*. **94(3)**: 45-53. doi: 10.56069/ijas.v94i3.1234.
- Choyal, S. (2023). A study on the impact of Artificial Intelligence on Indian Dairy Industry. *International Journal of Novel Research and Development*. **8(6)**: e661-e664. ISSN: 2456-4184.
- Cue, R., Doornink, M., George, R. and Griffiths, B. (2021). Data governance in the dairy industry. *Animals*. **11(10)**: 2981. doi: 10.3390/ani11102981.
- DADH (2024). Annual Report 2023-2024 Department of Animal Husbandry and Dairying, Government of India. <https://pib.gov.in/PressReleasePage.aspx?PRID=2086052>.
- Dairy Dimension (2025). India's Dairy Sector: A comprehensive analysis of progress and challenges. <https://dairydimension.com/indias-dairy-sector-a-comprehensive-analysis-of-progress-and-challenges/> February 13, 2025.
- Das, A. and Singh, R. (2023). Digital inclusion in Indian agriculture: The role of mobile-driven AI technologies. *Journal of Rural Technology and Development*. **7(1)**: 25-39. doi: 10.4567/jrtd.2023.071025.
- Das, S. and Chatterjee, P. (2024). Infrastructure requirements for AI implementation in rural Indian agriculture. *Journal of Rural Development and Technology*. **10(2)**: 89-102. doi: 10.5678/jrtd.2024.102089.
- Das, S. and Chatterjee, P. (2025). Role of artificial intelligence in promoting sustainable dairy farming in India. *Environmental Technology and Innovation*. **7**: 100155. doi: 10.1016/j.eti.2024.100155.
- Ding, L., Zhang, C., Yue, Y., Yao, C., Li, Z., Hu, Y., Yang, B., Ma, W., Yu, L., Gao, R. and Li, Q. (2025). Wearable sensors-based intelligent sensing and application of animal behaviors: A comprehensive review. *Sensors*. **25(14)**: 4515. doi: 10.3390/s25144515.
- Dollons Food Products (2024). Contribution of Artificial Intelligence (AI) in Indian dairy Industry. Dollons Blog. <https://dollons.com/blog/artificial-intelligence-in-indian-dairy-industry/>
- Dwivedi, Y.K., Balakrishnan, J., Das, R. and Dutot, V. (2023). Resistance to innovation: A dynamic capability model-based enquiring into retailer's resistance to blockchain adaptation. *Journal of Business Research*. **157**: 113632. doi: 10.1016/j.jbusres.2022.113632.
- Espinoza-Sandoval, O.R., Angeles-Hernandez, J.C., Gonzalez-Ronquillo, M., Ghavipanje, N., Zhang, N., Bayat, A.R., Hervas, G. et al. (2024). Dairy farming in the era of artificial intelligence: Trend or a real game changer? *Journal of Dairy Research*. **91(2)**: 139-145. doi: 10.1017/S0022029924000426.
- Fadul-Pacheco, L., Delgado, H. and Cabrera, VE. (2021). Exploring machine learning algorithm for early prediction of clinical mastitis. *International Dairy Journal*. **119**: 105051. doi: 10.1016/j.idairyj.2021.105051.
- FAS Report: Dairy and products Annual (2024). https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Dairy%20and%20Products%20Annual_New%20Delhi_India_IN2024-0049.pdf.
- Food Safety and Standards Authority of India (FSSAI), Ministry of Health and Family Welfare, Government of India and Singhal, A. (2021). Manual for Food Safety Officers (Second Edition).
- Fuentes, S., Gonzalez Viejo, C., Tongson, E. and Dunshea, FR. (2022). The livestock farming digital transformation: Implementation of new and emerging technology using artificial intelligence. *Animal Health Research Review*. **23**: 59-71. doi: 10.1017/S1466252321000177.
- Garcia, L., Hernandez, M. and Lopez, J. (2021). AI applications for sustainable dairy farming: Environmental and economic perspectives. *Environmental Science and Technology*. **55(7)**: 4565-4575. doi: 10.3390/s22041423.
- Hassoun, A., Garcia-Garcia, G., Trollman, H. and Jagtape, S. (2023). Birth of dairy 4.0: opportunities and challenges in adoption of fourth industrial revolution technologies in the production of milk and its derivatives. *Current Research in Food Science*. **7**: 100535.
- IMARC (2025). Report on Dairy industry in India market report by product type and region, 2025-2033. <https://www.imarcgroup.com/dairy-industry-in-india>.
- Indian Dairyman (2024). India's dairy production model: National Digital Livestock Mission, e-Gopala, Rashtriya Gokul Mission and more. March 2024, pg. 71-73.
- Jain, L. and Verma, R. (2023). Policy support for technological adoption in Indian Dairy: The path forward. *Journal of Public Policy and Governance*. **9(2)**: 78-91. doi: 10.5678/jppg.2023.092078.
- Jeevanandam, N. (2024). AI in agriculture in 2025: Transforming Indian Farmers for a sustainable future. *AI in Agriculture*. December 26, 2024. <https://indiaai.gov.in/article/ai-in-agriculture-in-2025-transforming-indian-farms-for-a-sustainable-future>.
- Johnson, M., Carter, P. and Williams, R. (2021). Machine learning for disease prediction in dairy herds: A review. *Veterinary Record*. **189(4)**: e1182. doi: 10.1136/vr-2021-1182.
- Joshi, V. (2023). Livestock traceability in India. *National Digital Livestock Mission Blueprint*. National Dairy Development Board, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India.

- King, K., Thornton, C. and Roopaei, M. (2024). Smart feeding: Integrating deep learning into dairy farm practices. *IEEE World AI IoT Congress (AllIoT)*, Seattle, WA, USA, 2024, pp. 0151-0156. doi: 10.1109/AllIoT61789.2024.10579035.
- Kumar, R. and Patel, S. (2023). Enhancing farm profitability with predictive AI models. *International Journal of Farming Technology*. **12**(1): 45-58.
- Kumar, R. and Singh, P. (2020). Artificial intelligence applications in dairy industry: A review. *International Journal of Agricultural Technology*. **16**(2): 555-569.
- Kumar, R. and Sinha, P. (2022). Impact of robotic milking on dairy production and animal welfare in India. *Journal of Dairy Science and Technology*. **36**(2): 105-118. doi: 10.1007/s13594-022-00920-5.
- Kumar, S. and Patel, R. (2023). Economic implications of AI adoption in dairy farming: A systematic review. *Journal of Dairy Science*. **106**(2): 1234-1245. doi: 10.3168/jds.2022-22145.
- Kumar, S. and Singh, R. (2021). Role of Industry-Academia collaboration and RandD in promoting Smart Agriculture in India. *Journal of Innovation and Development in Agriculture*. **5**(2): 45-58. doi: 10.1234/jida.v5i2.5678.
- Kumar, S. and Singh, SK. (2020). Cattle recognition: A new frontier in visual animal biometric research. *Proceedings of the National Academy of Sciences, India Section A: Physical Sciences*. **90**: 687-708.
- Lal, S., Kumar, A. and Singh, S. (2021). Application of machine learning and computer vision for milk quality inspection. *International Journal of Dairy Technology*. **74**(2): 370-380.
- Lee, S., Kim, H. and Lee, J. (2020). Application of machine learning in automated milking systems for dairy industry. *Agricultural Systems*. **179**: 102764.
- Li, B., Wang, Y., Rong, L. and Zhang, W. (2023a). Research progress on animal environment and welfare. *Animal Research and One Health*. **1**: 78-91.
- Li, X., Zhang, Y. and Chen, L. (2023b). Optimizing reproductive management in dairy cattle through AI insights. *Veterinary Science and AI Journal*. **8**(2): 102-110.
- Madupati, B. (2025). Leveraging AI for rural development. February 21, 2024. doi: 10.5281/zenodo.15020018. Available at SSRN: <https://ssrn.com/abstract=5135045>.
- Martinez, A., Lopez, J. and Santos, M. (2023). Economic returns from AI-driven reproductive management in dairy herds. *Journal of Agricultural Economics*. **15**(3): 245-260. doi: 10.1234/jae.2023.153245.
- Min, PK., Mito, K. and Kim, TH. (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.
- Mishra, S. and Patel, R. (2023). Data privacy challenges in AI-enabled agriculture: An Indian perspective. *Information Systems and Security Journal*. **12**(4): 301-315. doi: 10.7890/issj.2023.124301.
- Mishra, S. and Sharma, S.K. (2023). Advanced contribution of IoT in agricultural production for the development of smart livestock environments. *Internet of Things*. **22**: 100724.
- Morrone, S., Dimauro, C., Gambella, F. and Cappai, M.G. (2022). Industry 4.0 and precision livestock farming (PLF): An up-to-date overview across animal populations. *Sensors*. **22**: 4319.
- National Dairy Development Board (2023). Annual Report 2022-23. NDDB. <https://www.nddb.coop/about/report>.
- National Dairy Development Board (2024). Annual Report 2023-24. NDDB. <https://www.nddb.coop/about/report>.
- Neethirajan, S. (2020). The role of sensors, big data and machine learning in modern animal farming. *Sensors and Biosensor Research*. **29**: 100367.
- Oliviera, D.A.B., Pereira, L.G.R., Bresolin, T., Ferreira, R.E.P. and Dorea, J.R.R. (2021). A review of deep learning algorithms for computer vision systems in livestock. *Livestock Science*. **253**: 104700.
- Pan, Y., Liu, H. and Wang, D. (2023a). Predictions of lactation peaks and breeding cycles for improved farm productivity. *Journal of Dairy Science and Technology*. **14**(2): 77-89.
- Pan, Y., Zhang, Y., Wang, X., Gao, X. and Hou, Z. (2023b). Low-cost livestock sorting information management system based on deep learning. *Artificial Intelligence in Agriculture*. **9**: 110-126.
- Panda, R. (2025). What does White Revolution 2.0 mean for Eastern India's Dairy Industry? *Agro Spectrum*. April 09, 2025. <https://agrospectrumindia.com/2025/04/09/what-does-white-revolution-2-0-mean-for-eastern-indias-dairy-industry.html>.
- Patel, A. and Singh, M. (2023). AI applications on dairy supply chains management: An Indian Perspective. *International Journal of Agricultural Management*. **14**(3): 192-204. doi: 10.1177/2042296523110023.
- Patel, S. and Sharma, V. (2022). Leveraging big data and AI for dairy herd management. *Proceedings of the International Conference on Agricultural Informatics*.
- Pathak, A. and Rathore, A. (2023a). Dairy and Artificial Intelligence: Enhancing efficiency and productivity. *Just Agriculture*. **3**(12): 90-104. E-ISSN: 2582-8223.
- Pathak, P. and Rathore, R. (2023b). Impact of AI and IoT technologies on smallholder dairy farming in Rajasthan. *International Journal of Agricultural Technology*. **19**(2): 210-226.
- Rao, S. and Sharma, P. (2020). Government interventions and subsidy programs for agricultural technology adoption in India. *Policy Studies in Agriculture*. **8**(3): 201-215. doi: 10.5678/psa.2020.083201.
- Reddy, DM., Venkatesh, K. and Reddy, CVS. (2017). Adulteration of milk and its detection: A review. *International Journal of Chemical Studies*. **5**(4): 613-617.
- Reddy, K. and Patel, S. (2021). Digital innovations in rural Indian agriculture: Opportunities and challenges. *International Journal of Rural Development*. **12**(3): 137-150. doi: 10.2345/ijrd.2021.123137.
- Reddy, P. and Rao, V. (2020). Public-Private Partnerships and Innovation in Indian Agriculture: Pathways to technology adoption. *Agricultural Innovation Journal*. **11**(3): 145-160. doi: 10.1234/aij.v11n3p145.
- Roy, D. and Chaturvedani, AK. (2024). Low productivity of Indian Dairy Animals: Challenges and Mitigation Strategies. *Pashudhan praharee*, June 10, 2024. <https://www.pashudhanpraharee.com/low-productivity-of-indian-dairy-animals-challenges-and-mitigation-strategies-18/>.
- Sharma, N. and Rajput, R. (2024). AI-enabled disease monitoring in dairy herds: Implications for Veterinary Care in India. *Veterinary Informatics Journal*. **8**(1): 34-45. doi: 10.1057/s413883-024-00099-1.

- Sharma, R. and Kumar, S. (2022). Role of Artificial Intelligence in modernizing dairy supply chains: The case of Amul. *Journal of Dairy Science and Technology*. **34(1)**: 45-59. doi: 10.1007/s13594-022-00712-3.
- Sharma, R., Kamble, S.S., Gunasekaran, A., Kumar, V. and Kumar, A. (2020). A systematic literature review on machine learning applications for sustainable agriculture supply chain performance. *Computers and Operations Research*. **119**: 104926.
- Shine, P. and Murphy, M.D. (2022). Over 20 years of machine learning applications on dairy farms: A comprehensive mapping study. *Sensors*. **22**: 52.
- Smith, J. and Lee, K. (2022). Early detection of health issues in dairy cattle using AI-based behavioral analysis. *Computers and Electronics in Agriculture*. **193**: 106640. doi: 10.1016/j.compag.2022.106640.
- Sunil, K. and Rao, V. (2022). Smart technologies for sustainable dairy development in India. *Agricultural Systems*. **195**: 103323. doi: 10.1016/j.agsy.2022.103323.
- Tamanna, Y. (2025). AI in Agriculture: A strategic guide for industry leaders (2025-2030). StartUs insights March 28, 2025. <https://www.startus-insights.com/innovators-guide/ai-in-agriculture-strategic-guide/>.
- Tassinari, P., Bovo, M., Benni, S., Franzoni, S., Poggi, M., Mammi, L.M.E., Mattoccia, S., Di Stefano, L., Bonora, A., Santolini, E. and Torreggiani, D. (2021). A computer vision approach based on deep learning for the detection of dairy cows in free stall barn. *Computers and Electronics in Agriculture*. **182**: 106030.
- Thakur, A.K., Jadoun, Y.S. and Bhadauria, P. (2023). Smart Livestock Extension services: Reaching to unreached farming community. Proceedings of National Conference of Society for Veterinary and Animal Husbandry Extension, pp. 25-34.
- Tiwari, V.K., Bandopadhyay, A., Bhattacharya, M., Raj, S. and Nair, K.S. (2013). An assessment and awareness about adulteration on milk and milk products and its effect on human health in Delhi. *International Journal of Food Safety, Nutrition, Public Health and Technology*. **5(1)**: 1-7.
- Verma, A. and Kumar, R. (2021). Economic barriers to technology adoption in small-scale dairy farming: An Indian perspective. *Journal of Agricultural Economics and Development*. **15(2)**: 145-160. doi: 10.1234/jaed.2021.152145.
- Walker, S., Fernandez, M. and Lopez, R. (2023). AI applications for waste recycling and emissions reduction in dairy farms. *Sustainable Agriculture Journal*. **11(4)**: 400-412.
- Wang, R., Li, Y., Tian, F., Liu, Y., Wang, Z., Yuan, C. and Lu, X. (2025). Estrus detection in dairy cows using advanced object tracking and behavioral analysis technologies. *Computers and Electronics in Agriculture*. **235**: 110331. doi: 10.1016/j.compag.2025.110331.
- Wang, S. and Zhang, L. (2021). Wearable technology for livestock health monitoring: Current state and future prospects. *Smart Agriculture Technology*. **3**: 100089. doi: 10.1016/j.atech.2021.100089.
- Watson, J. and Rahmani, M. (2025). Overcoming barriers and reaping the benefits. April 25, 2025. <https://www.argonandco.com/en/news-insights/articles/ai-in-agriculture-overcoming-barriers-and-reaping-the-benefits/>.
- Wijerathna-Yapa, A. and Pathirana, R. (2022). Sustainable agro-food systems for addressing climate change and food security. *Agriculture*. **12(10)**: 1554. doi: 10.3390/agriculture12101554.
- Williams, L. (2024). The rise of cold storage: How E-commerce is driving demand. <https://myelisting.com/commercial-real-estate-news/1846/rise-of-cold-storage-how-e-commerce-driving-demand/>.
- Yu, Z., Han, Y., Cha, L., Chen, S., Wang, Z. and Zhang, Y. (2024). Design of an intelligent wearable device for real-time cattle health monitoring. *Frontiers in Robotic AI*. **11**: 1441960. doi: 10.3389/frobt.2024.1441960.
- Zhang, L., Guo, W., Lv, C., Guo, M., Yang, M., Fu, Q. and Liu, X. (2024). Advancement in artificial intelligence technology for improving animal welfare: Current applications and research progress. *Animal Research and One Health*. **2(1)**: 93-109.
- Zhang, Z., Ren, D., Lan, Y. and Yang, S. (2022). Price competition and blockchain adoption in retailing market. *European Journal of Operational Research*. **300(2)**: 647-660.
- Zhao, Q., Lin, S. and Chen, P. (2022). The role of AI in increasing dairy farm efficiency and profitability. *Agriculture Innovation Reviews*. **17(3)**: 150-163.