

# Education about smart dairy farming using artificial intelligence

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## ABSTRACT

Modern dairy farming is undergoing a paradigm shift toward smarter, more sustainable livestock management driven by the integration of artificial intelligence (AI) and computer vision technologies. These innovations are transforming traditional practices, enabling more precise, efficient, and humane approaches to herd management. This review examines how AI technologies, particularly computer vision, machine learning, and sensor-based systems, are enhancing core areas of dairy operations, including cattle identification, health monitoring, disease detection, and reproductive management. Advanced image-based systems now enable contactless identification, improving animal welfare and operational precision. AI-enabled health surveillance tools support early disease detection, reducing veterinary costs and improving herd productivity. In reproductive care, AI facilitates accurate estrus detection and pregnancy monitoring using data from wearable sensors and cameras, optimizing insemination timing and calving outcomes. Integration with smart farm platforms also allows real-time decision-making for feeding, barn conditions, and logistics, thereby boosting profitability and environmental sustainability. Despite significant progress, challenges such as infrastructure gaps, high costs, and data governance remain. This review also proposes a roadmap for inclusive AI adoption and emphasizes the need for interdisciplinary education and ethical deployment. By synthesizing recent innovations and addressing critical barriers, the paper presents AI as an enabler of intelligent and efficient dairy farming. As global dairy demand rises, AI offers scalable solutions to improve productivity while supporting long-term environmental and animal welfare goals.

**Keywords:** artificial intelligence, computer vision, precision livestock farming, dairy herd management, animal welfare

## INTRODUCTION

Dairy farming remains a vital component of the global food production system, supplying essential nutrients to billions of people worldwide. However, as the demand for animal-derived products such as milk and meat continues to rise due to population growth and changing dietary preferences, the dairy industry faces mounting pressure to increase productivity, improve animal welfare, and reduce environmental impact. Traditional farming methods, although foundational, often fail to meet these modern challenges. Issues such as labor shortages, rising operational costs, disease outbreaks, and the need for sustainable resource management underscore the urgency for innovative solutions. In this context, artificial intelligence (AI) has emerged as a transformative force, offering a suite of intelligent technologies that can enhance decision-making, optimize operations, and improve overall farm performance.

AI has evolved from a concept centered on enabling computers to perform tasks requiring human intelligence into a broad, interdisciplinary technology encompassing machine learning (ML), deep learning (DL), and natural language processing (NLP). ML allows systems to learn patterns from data and make predictions without being explicitly programmed for every scenario. It includes supervised learning (used for prediction and classification), unsupervised learning (for data mining and clustering), and reinforcement learning (for decision-making and control tasks). DL, a subset of ML, employs multilayer neural networks, such as convolutional neural networks (CNNs) and recurrent neural networks, for complex tasks like image and speech recognition. NLP enables machines to interpret and generate human language, facilitating applications like sentiment analysis, machine translation, and dialogue systems. These AI subfields are widely applied across domains such as healthcare, agriculture, and education. Overall, AI is reconstructing industries by enhancing efficiency, accuracy, and problem-solving capabilities. AI applications in dairy farming encompass various aspects, including health monitoring, feeding optimization, reproductive management, and supply chain logistics.

Traditional cattle identification methods, such as ear tags and RFID systems, have long been used in dairy farming but are increasingly viewed as inefficient, error-prone, and stressful to animals. As the global population grows, the demand for milk and

meat surges, placing immense pressure on producers to increase productivity without expanding herd sizes. AI makes this possible by optimizing output per animal and improving operational efficiency. Emerging technologies such as the Internet of things (IoT), edge computing (EC), and distributed ledger technology (DLT) further enhance scalability, traceability, and system integrity. Ultimately, integrating AI into dairy farming supports a shift toward sustainable, ethical, and high-efficiency agricultural practices, positioning the industry to meet future challenges with innovative, data-driven solutions.

This review paper presents a comprehensive analysis of the transformative role of AI in dairy farming. It explores advancements in AI-driven technologies such as computer vision, ML, and precision tools applied to cattle identification, health monitoring, and breeding optimization. Emphasizing sustainability, profitability, and animal welfare, the review evaluates how these innovations enhance operational efficiency and environmental stewardship. Additionally, it addresses key implementation challenges and proposes a strategic roadmap for AI adoption. By synthesizing current developments, this paper underscores AI's potential to uplift dairy farming and shape a smart, ethical, and sustainable future for the global livestock industry.

## METHODOLOGY

This review systematically explores the transformative impact of AI on traditional dairy farming. A thorough literature search was conducted across databases, including Scopus, Web of Science, PubMed, and Google Scholar, using keywords like AI, precision livestock farming (PLF), and dairy herd management. Peer-reviewed articles and conference papers were selected based on their relevance to key areas such as cattle identification, health monitoring, disease detection, reproductive management, and smart farming integration. Emphasis was placed on studies featuring ML, sensor-based technologies, and real-time analytics. The review highlights practical applications, identifies existing knowledge gaps, and proposes a roadmap for responsible AI integration.

## HARNESSING ARTIFICIAL INTELLIGENCE TO MODERNIZE DAIRY FARMING

The dairy industry is undergoing a transformative shift with the adoption of AI, a foundational element of PLF. AI-driven tools such as robotic milking systems, smart feeding units, wearable sensors, and behavioral monitoring platforms are redefining traditional dairy practices. These technologies reduce manual labor, optimize management decisions, and enhance sustainability and animal welfare. Real-time livestock monitoring integrates data from thermal cameras, smart collars, and milk meters to track health metrics such as body temperature, mobility, and milk composition (Pathak & Rathore, 2023). AI algorithms use this data to detect early signs of disease, estrus, or lameness, enabling timely and targeted interventions. For example, gait analysis systems can detect lameness with high accuracy, while computer vision can identify behavioral stress linked to environmental stressors such as poor ventilation or stray voltage (Patel et al., 2022).

Robotic milking is among the most significant AI applications in modern dairy. These systems autonomously manage milking while gathering data on yield, quality, and udder health. By adapting routines to individual cows, they boost comfort and hygiene, both of which are tied to milk productivity (Pathak & Rathore, 2023). Similarly, automated feeding systems use AI to distribute feed tailored to each cow's needs, minimizing waste and improving digestion and yield. AI also enhances reproductive management by analyzing behavioral and physiological cues to detect estrus, predict calving, and optimize breeding, leading to higher conception rates with fewer hormonal treatments (Patel et al., 2022). In disease prevention, AI platforms detect anomalies in sensor data, guiding vaccination strategies and outbreak forecasting. Advanced tools such as facial recognition and AI-assisted diagnostics can even evaluate emotional states and pain levels, facilitating humane veterinary care (Hamadani et al., 2024). These capabilities reduce reliance on antibiotics and enhance welfare-based farming models.

Modern dairy farms are evolving into smart environments. AI controls climate systems, adjusting ventilation, lighting, and temperature to mitigate heat stress and optimize milk quality. GPS-enabled equipment and soil sensors also assist in sustainable on-farm fodder production by improving planting and irrigation practices. Across the supply chain, AI enhances food safety by tracking milk transportation and cold chain conditions. Inventory forecasting tools help reduce spoilage and overproduction (Pathak & Rathore, 2023). When integrated with blockchain, AI increases traceability, enabling consumers to verify product origin and ethical compliance. Agricultural extension services are similarly evolving; AI merges real-time sensor data with expert systems to provide farm-specific recommendations in feeding, breeding, and disease management (Hamadani et al., 2024). These tools support better genetics, efficient resource use, and sustainability. As global demand rises and environmental concerns intensify, AI and computer vision offer scalable alternatives to manual monitoring. Techniques like ML, DL, and predictive analytics support real-time disease detection, health monitoring, and strategic decision-making. Tools such as wearable sensors and imaging systems reduce antibiotic use by enabling early detection and improving individual animal care.

ML models, particularly CNNs, enhance AI capabilities in image-based diagnostics such as gait analysis and body condition scoring (Hossein-Zadeh, 2025). These technologies also support quality control in milk processing. Farms that adopt AI report measurable improvements, including up to 15% reductions in feed waste, 20% fewer disease outbreaks, and increased productivity. Environmental impacts are lowered through optimized inputs and reduced methane emissions. The future of dairy is moving toward intelligent systemization, where strategic deployment of AI and automation improves resilience, competitiveness, and sustainability. Massive data streams from cow behavior, feed, and milk yield are processed using ML to reveal trends and allow early interventions.

Melak et al. (2024) demonstrated that automating data analysis cuts interpretation time by 20%, improving efficiency and decision-making. Tools such as precision dairy farming platforms use real-time sensors to monitor vital signs and behavioral indicators for health and breeding (Vyas et al., 2022). However, a major challenge remains in fragmented, siloed data systems. To address this, Pakrashi et al. (2023) developed CowMesh, a FAIR-compliant, decentralized data platform that links biosensors (Krogstad & Hartschuh, 2024), robots, and applications like mastitis prediction. Advanced ML techniques such as random forests, support vector machines (SVM), and ensemble models further boost prediction accuracy. Thangavel et al. (2025) showed that combining SVM with clustering methods like k-means and K-nearest neighbors (KNN) enhances accuracy for both yield and disease forecasts. Explainable AI tools improve transparency by identifying key predictive variables.

## EMERGING DIGITAL TECHNOLOGIES TOWARDS A SUSTAINABLE AND INTELLIGENT DAIRY INDUSTRY

The dairy industry, a cornerstone of global agriculture, is undergoing a critical transformation to address growing demands for sustainability, transparency, and food security. Technological integration is reshaping operations across the entire dairy value chain. IoT enables farms to deploy connected sensors and wearable devices that monitor milk yield, animal health, feeding patterns, and environmental conditions. These data streams support continuous, real-time oversight of farm functions. EC complements this by processing data locally at the source, allowing rapid decision-making crucial for applications like estrus detection and automated milking (Alonso et al., 2020). DLT, especially blockchain, ensures traceable and tamper-proof records of milk production, storage, and distribution, boosting consumer trust and accountability. AI, in turn, enhances these systems by interpreting complex datasets from milking machines, biosensors, and environmental monitors. By leveraging ML and predictive analytics, farms can make informed decisions on feeding schedules, disease prevention, and herd health (Gulec, 2024). Tools like MilkingCloud provide intuitive dashboards that translate these data into actionable insights. Advanced techniques such as CNNs and SVM are being used effectively for mastitis detection, milk yield prediction, and body condition classification (Dilaver and Dilaver, 2024).

The automation of farm labor through robotics is also transforming operational efficiency. AI-powered robotic systems now perform labor-intensive tasks such as feeding, milking, and manure removal. For example, voluntary milking systems increase both cow comfort and milk yield, while simultaneously monitoring animals for signs of illness or distress using computer vision and sensor data (Dilaver & Dilaver, 2024). These technologies support a more humane, responsive farming model and reduce disease spread through timely interventions. Integrated AI-IoT systems optimize water, feed, and energy use by adapting distribution to real-time needs, contributing to resource efficiency and sustainability (Vlaicu et al., 2024). PLF uses smart sensors and predictive models to minimize greenhouse gas emissions and ensure animal welfare. Farmers can now customize care based on individual animal data, aligning ethical treatment with high productivity standards. Importantly, such technologies are increasingly accessible to small and medium-sized farms due to declining sensor costs and improved connectivity. A study in Romania showed that adopting AI, IoT, and robotic process automation led to a 19% increase in profitability, a 21% productivity boost, and a 22% reduction in environmental impact (Micle et al., 2021). Other digital tools like expert systems, geographic information systems (GIS), and web-based platforms enhance decision-making and logistics. GIS supports pasture mapping and fodder planning, while GPS enables real-time tracking of livestock and milk transport (Dayoub et al., 2025; Jain et al., 2005). AI-based models using neural networks and fuzzy logic are being applied in feed optimization and health risk analysis, enabling farms to manage uncertainty effectively.

Recent innovations like the integrated approach to dairy farming (IA-DF) exemplify the power of multi-tech integration. By combining IoT, EC, and DL architectures such as VGG16 and Bi-LSTM, IA-DF systems can identify behavioral patterns like step count and lying time with over 96% accuracy, supporting proactive health management (Pandey and Mishra, 2024). Post-farm applications of AI now include storage optimization, spoilage prediction, and product quality control. Smart tools like drones, LED systems, and mobile apps further enhance sustainability efforts. Public initiatives, such as Livestock Week and Expoleche in Central America, underscore the global momentum for technological adoption in dairy (Esquivel, 2019). Ultimately, the convergence of IoT, EC, DLT, and AI is uplifting dairy farming by enabling data-driven, real-time, and ethical practices. These innovations not only improve productivity and animal welfare but also equip farms, regardless of size, to thrive in a rapidly evolving agricultural landscape (Gupta, 2024; Neculai-Valeanu et al., 2025).

## CATTLE IDENTIFICATION AND TRACKING THROUGH COMPUTER VISION AND ARTIFICIAL INTELLIGENCE

Modern dairy farming is undergoing a shift through the integration of AI and computer vision, leading to a new era of precision livestock management. These technologies are replacing traditional manual practices with automated, data-driven systems that enhance operational efficiency, animal welfare, and sustainability. Core applications include automated cattle identification, behavioral monitoring, health diagnostics, and precision feeding strategies. One of the most significant innovations is image-based cattle identification using CNNs, which analyze facial features, coat patterns, and body shapes for non-invasive, high-accuracy identification. This method reduces animal stress and eliminates the errors common in tagging systems like RFID and ear tags (de Castro et al., 2025; Rajagopal et al., 2025). These vision systems also support real-time monitoring of health and behavior, enabling early detection of issues such as irregular feeding, mobility anomalies, or stress indicators.

When integrated with farm management platforms like MilkingCloud, image-based monitoring updates animal records automatically, facilitating timely, evidence-based decisions in areas like feeding and disease control (Michielon et al., 2024). CNNs are further applied in detecting lameness, heat stress, and disease symptoms, minimizing the need for manual inspections or wearables. AI can even assess emotional states using behavioral data and environmental cues through affective state frameworks, interpreting signs of discomfort due to heat or social isolation (Dawkins, 2025). AI-powered predictive analytics forecast milk yields, detect estrus, and anticipate calving. For instance, platforms by Cainthus and Ever.Ag combine video feeds with predictive models to issue early alerts about feeding deviations or reproductive milestones (Connolly, 2025). AI also drives precision feeding by personalizing diets according to individual weight, age, and lactation stage, improving feed efficiency and reducing waste (Zhang et al., 2024).

Smart barns equipped with AI systems autonomously manage climate conditions, temperature, ventilation, humidity, and lighting, to optimize cow comfort and health, which positively affects productivity (Aharwal et al., 2023). Robotic milking systems, enhanced with AI, further streamline milking schedules and hygiene, reducing labor demands while improving outcomes. Wearable sensors remain vital for tracking temperature, rumination, and movement, with AI interpreting these data to detect early symptoms of diseases like mastitis or lameness. Additionally, non-invasive phenotyping tools, such as video analytics and 3D imaging, enable remote evaluation of body condition, weight, and gait (de Castro et al., 2025). For example, using a 360° camera system in a free-stall barn achieved 93.1% accuracy in behavior detection, while spatial mapping revealed patterns potentially indicating stress or orthopedic issues (Kurras & Jakob, 2024).

Advanced object detection models like YOLOv8 and ByteTrack have enhanced cattle tracking and markerless identification. Though visual similarity among animals remains a challenge, high-resolution imaging and 3D models are mitigating this (Michielon et al., 2024). Tools like RCNN Inception V3 further improve diagnostic precision by analyzing specific body parts and postures (Lima et al., 2021). Data integration is key to scaling these technologies. Projects such as agriProKnow have developed semantic data warehouses to unify diverse farm data, allowing actionable analytics for disease prevention and quality control (Schuetz et al., 2018). Despite these advances, a review of the Dutch dairy sector highlights the need for more intuitive interfaces and cognitive tools to increase adoption (Kassahun et al., 2022).

A particularly impactful application of AI is in computer vision, an advanced form of image processing. This technology enables automated cattle identification and behavioral monitoring, reducing human error and enhancing record-keeping and health surveillance. Melak et al. (2024) developed systems that identify individual cattle using visual markers, improving traceability and long-term behavioral analysis. Such systems can detect early signs of stress or illness, allowing for timely interventions. For example, CattleEye employs 2D cameras to analyze gait and detect locomotion issues, helping reduce veterinary costs and improve welfare (Connolly, 2024). Similarly, Cattle Care monitors milking routines for operational anomalies, and ElectroFai acts as a “digital shepherd,” ensuring compliance with welfare standards.

## ADVANCEMENTS IN HEALTH MONITORING AND DISEASE DETECTION THROUGH ARTIFICIAL INTELLIGENCE

AI and ML are fundamentally transforming dairy farming, particularly in health monitoring and disease detection. These technologies form the backbone of smarter, data-driven farm management by leveraging large datasets from sensors, imaging systems, and behavioral monitors. They enable early disease detection, optimize operations, and support evidence-based decision-making across the production cycle. One of AI's most impactful applications in dairy farming is the early detection of prevalent diseases such as mastitis and lameness. Mastitis, a common and costly inflammatory disease affecting milk yield and quality, can now be identified before clinical symptoms appear through ML algorithms that analyze sensor data, milk conductivity, somatic cell counts, and temperature, allowing timely interventions that reduce both transmission and losses (Lima-Campêlo et al., 2024).

Beyond real-time diagnostics, predictive analytics driven by ML assess historical and live data to flag high-risk animals, enabling proactive and personalized care. This approach minimizes antibiotic use, reduces veterinary costs, and improves animal welfare. For instance, image-based ML models for weight estimation provide a non-invasive method to track growth, optimize feed efficiency, and guide medication dosages (Nogoy et al., 2021). AI is also enhancing reproductive efficiency and feed management. Fertility-tracking algorithms now outperform traditional methods in predicting estrus and optimal breeding windows, leading to improved conception rates and fewer failed inseminations. Nutrient analysis powered by AI customizes feed based on lactation stages, reducing waste while maximizing yield (Veeneman, 2025). Robotic milking systems embedded with sensors monitor milk composition and machine performance in real time, detecting signs of infection, stress, or system malfunctions and supporting predictive maintenance.

Lameness detection has greatly improved with AI integration. Conventional visual assessment is prone to human error, while modern systems use accelerometers, radar, and computer vision for continuous, accurate monitoring. A multimodal AI model developed by Dhaliwal et al. (2025) combines facial expression analysis with motion tracking using DenseNet-121 and long short-term memory networks, achieving 99.55% accuracy. This model identified prolonged resting during active periods as a key indicator of lameness. Siachos et al. (2024) advocated for longitudinal studies to develop farm-specific baselines and improve detection accuracy. However, despite mastitis being a top concern, a Québec survey revealed that only 10% of farmers quarantine new animals, indicating a gap in biosecurity practices (Lima-Campêlo et al., 2024). AI tools can bridge this by tracking movements and exposure risks.

Decision-support systems like the ThinkDairy Hub exemplify AI's diagnostic capabilities. Using a KNN algorithm, it evaluates 21 physiological and environmental variables to detect heat stress and subclinical mastitis (Nogoy et al., 2021). AI is also making strides in veterinary diagnostics. DL models such as CNNs, artificial neural networks, and partial least squares discriminant analysis enhance image-based diagnostics, increasing both speed and accuracy. AI-based systems now outperform traditional methods in sensitivity and specificity (Ali, 2023). AI's role extends to sustainability. It optimizes water and energy use, supports inventory forecasting, and reduces waste (Veeneman, 2025). With growing consumer demand for transparency, companies like Sainsbury's are investing in AI-driven solutions for traceability and welfare. Emerging research, including biomarker analysis for *Prototheca* spp.-induced mastitis, links AI with biomedical data for more precise diagnostics (Priyashantha & Vidanarachchi, 2024). In conclusion, AI and ML facilitate sustainability and biosecurity, offering intelligent, ethical, and scalable solutions for the future of agriculture.

## OPTIMIZING DAIRY CATTLE BREEDING THROUGH ARTIFICIAL INTELLIGENCE AND PRECISION TECHNOLOGIES

The success of dairy cattle breeding programs hinges on accurate estrus detection and effective gestation monitoring. Traditionally dependent on manual observation, these processes are labor-intensive and prone to human error, often resulting in missed reproductive opportunities. Today, the integration of ML, image processing, and decision support systems (DSS) is redefining reproductive management in dairy farming by delivering greater precision, efficiency, and sustainability. ML algorithms can detect subtle physiological and behavioral cues of estrus, such as changes in body temperature, mounting behavior, vocalizations, and activity levels, that are frequently overlooked by humans. These indicators are monitored through sensors and imaging tools, enabling real-time estrus detection and more accurately timed artificial insemination (Nagahara et al., 2024). As a result, conception rates improve while failed inseminations decline, lowering costs and increasing reproductive efficiency. ML tools also enhance gestation monitoring by analyzing movement and feeding patterns, offering early warnings of calving and potential complications, critical for both maternal and calf health.

When integrated with digital farm platforms like MilkingCloud, these technologies generate actionable insights for optimizing breeding schedules and herd management. This supports higher reproductive success and long-term genetic improvement by enabling data-driven selection for traits like disease resistance, milk yield, and feed efficiency, boosting productivity and sustainability. For example, Australia has implemented a combined knowledge discovery from databases (KDD) and intelligent decision support system (IDSS) to identify optimal mating pairs based on large-scale data. This adaptable KDD-IDSS framework supports high-precision, profitable breeding decisions (Balhara et al., 2021). A notable AI application in breeding is the pregnancy probability diagnostic model (PPDM), which analyzes static images of the external uterine opening to determine optimal insemination timing. Accessible via a web-based interface, PPDM is especially useful for less experienced users. Field testing yielded to 76.2% accuracy and precision, with 100% recall and an F-score of 0.86 at a 70% pregnancy probability threshold (Nagahara et al., 2024).

Feed conversion efficiency, a key breeding trait, is also being redefined using AI. Data mining techniques now link genetic markers with performance outcomes, enabling the identification of high-efficiency, low-impact animals. Globally, AI adoption in livestock systems is accelerating, particularly in estrus prediction, disease detection, and behavioral monitoring. Countries like the U.S. and the Netherlands lead this research growth (Balhara et al., 2021). Computer vision models such as CNNs facilitate real-time decisions, while advanced DSS tools allow farmers to simulate breeding outcomes and allocate resources effectively. In summary, AI, ML, and DSS are transforming reproductive management into dairy farming, enhancing genetic gain, sustainability, and profitability while improving animal welfare.

## SUSTAINABLE DAIRY FARMING THROUGH AI-POWERED RESOURCE OPTIMIZATION

The integration of cutting-edge technologies, namely image processing, computer vision, and ML, is transforming the global dairy industry. These innovations automate routine tasks, reduce labor dependency, and enable real-time, data-driven decision-making. As a result, dairy operations are becoming more precise, efficient, and resilient, able to meet rising demands from a growing global population while minimizing environmental impact. Feeding practices are increasingly customized using ML models that adjust nutritional inputs based on lactation stage and historical performance. This increases milk yield and reduces feed waste. Robotic milking systems exemplify the physical integration of AI: computer vision and ML detect udder placement and track milk flow, adjusting suction for optimal output while reducing stress (Singh et al., 2021). Virtual reality and AI-based translation tools are also being used to train and support multilingual farm staff (Melak et al., 2024), fostering improved workforce communication on large farms.

AI plays a vital role in advancing sustainable dairy practices. Predictive analytics help optimize water use, feed allocation, and fertilizer application. For instance, AI systems can estimate exact fertilizer needs, maximizing pasture output while minimizing runoff and environmental harm (Vargas-Bello-Pérez et al., 2024). AI also synthesizes weather forecasts and sensor data to adjust barn ventilation, hydration, and feeding schedules, reducing the carbon footprint and enhancing climate resilience. Achieving the UN sustainable development goals in agriculture will require AI adoption. Haribabu et al. (2025) proposed integrated frameworks combining EC, robotics, and blockchain to track inputs, optimize feed/water usage, and ensure traceability. AI also supports

intelligent supply chains through demand forecasting and adaptive logistics. Hamid et al. (2023) concluded that AI is no longer futuristic; it is essential for automating tasks, optimizing resources, and improving long-term planning in livestock production.

In regions like Latin America, where veterinary access and climate stability are limited, AI offers scalable solutions. Vargas-Bello-Pérez et al. (2024) emphasized that IoT, data fusion, and ML improve productivity and sustainability, especially in ruminant farming. An example of successful predictive modeling is provided by Sugiono et al. (2016), who used a back propagation neural network optimized via a genetic algorithm to predict milk output based on environmental and physiological data. The model achieved high accuracy using sigmoid transfer functions and sensitivity analysis revealed heart rate, body temperature, and humidity as top predictors. Heat stress, a growing concern due to climate change, has been addressed by Fuentes et al. (2020). They developed models using four years of robotic milking data to forecast performance under heat stress. Two models, one for heat-tolerant cows and another for the general herd, both achieved high accuracy ( $R \approx 0.86-0.87$ ), helping farms maintain productivity and welfare during extreme weather.

Despite upfront costs, the long-term benefits of AI integration in dairy farming are substantial. AI improves labor efficiency, enhances herd planning, and reduces resource waste. García-Méndez et al. (2023) emphasized the value of transforming raw sensor data into actionable insights for breeding, health monitoring, and overall management, boosting profitability while supporting environmental goals. With the global population expected to exceed 9 billion by 2050, smart dairy systems are seen as key to food security. Smart dairy farming, leveraging AI, IoT, and connectivity, promises to meet growing dairy demand. Nleya and Ndlovu (2022) showed that ML-based systems optimize operations using data from robotic milking, feeders, and health monitors, leading to better productivity and sustainability.

Historically, productivity in dairy was driven by genetic, nutritional, and veterinary advances. But with labor shortages, especially skilled ones, AI is filling the gap. Singh et al. (2021) noted that decreasing microprocessor costs and the rise of expert systems have enabled affordable automation, including for estrus detection and behavior analysis. These systems allow real-time, individualized animal management while aligning with growing consumer demands for ethical treatment and transparency. AI also enhances welfare and sustainability by providing non-invasive monitoring tools. Dutt et al. (2024) found that biosensors and DL models enable the detection of metabolic and digestive issues. Kashyap and Deshmukh (2023) highlighted the value of wearables that detect illness early and reduce unnecessary treatments, contributing to lower environmental impact.

One of the most comprehensive AI platforms is the dairy farm management system (DFMS), as described by Amarnath and Leelavathi (2025). DFMS integrates AI, IoT, ML, and computer vision to manage milk production, feeding, breeding, finances, and inventory. Smart milking machines adjust routines based on each cow's physiological status, while precision feeding systems tailor rations in real time. Wearables monitor vital signs, and computer vision assesses gait and posture. These data feed into ML models that predict yield and health risks. Alerts enable proactive management, while cloud-connected dashboards provide mobile access for farm operators. System scalability, cybersecurity, and IoT compatibility ensure long-term adaptability (Amarnath & Leelavathi, 2025).

At McGill University, the WELL-E Chair, led by Elsa Vasseur and Abdoulaye Baniré Diallo, applied AI and remote sensing to detect behavioral anomalies linked to stress or illness. Supported by Dairy Farmers of Canada and Lactanet, this initiative is being rolled out across Quebec farms and has trained over 50 students in digital agriculture (Nadeau, 2024). In the beef sector, AI tools optimize breeding, nutrition, and disease prevention. García (2025) highlighted how genomics and predictive models are improving disease resistance and feed efficiency, while blockchain enhances traceability and food safety.

## ARTIFICIAL INTELLIGENCE-BASED FRAMEWORK FOR LIVESTOCK WELFARE

AI and image processing technologies are transforming modern dairy farming, reshaping it into a more efficient, ethical, and data-driven enterprise. Traditional manual practices are rapidly being replaced by automated systems that enable continuous animal monitoring, proactive health interventions, and individualized care (Barraclough & Haskell, 2021). Central to this transformation is the use of ML algorithms for early disease detection. For instance, AI-driven computer vision systems analyze real-time video feeds to identify symptoms such as udder asymmetry or swelling, early indicators of mastitis, allowing for timely treatment and minimizing spread (Neethirajan, 2022). These technologies not only improve health outcomes but also align with growing societal and consumer expectations for humane livestock care. Behavioral monitoring further enhances welfare, as AI tracks stress-related activities like excessive lying or feed refusal, offering insights that support both ethical treatment and operational efficiency.

Beyond health, AI plays a critical role in precision nutrition, using data such as body condition scores, lactation phase, and feeding patterns to optimize diets. AI platforms from companies like Connecterra and Vyla process real-time metabolic data to tailor nutritional plans that reduce the risks of disorders like ketosis and acidosis while enhancing milk yield and minimizing feed waste (Akinsulie et al., 2024). Automated feeding systems, guided by predictive algorithms, distribute precise rations based on environmental and physiological variables. This not only improves feed efficiency but also lowers labor demands and greenhouse gas emissions. AI also modernizes veterinary diagnostics. From interpreting radiographs and MRIs to real-time analysis of biometric sensor data, AI systems enhance the speed and accuracy of diagnosis (Albadrani et al., 2024). These tools allow veterinarians to create personalized treatment strategies based on the unique physiological and genetic makeup of each animal, marking a significant leap toward precision veterinary medicine.

A particularly groundbreaking area is the emotional assessment of livestock, long a challenge due to the subjective nature of interpreting animal behavior. AI, integrated with computer vision and audio analysis, can now detect affective states like fear or discomfort through facial recognition systems such as the facial action coding system and thermal imaging, which track subtle

changes in expression and temperature (Neethirajan, 2022). These insights enable predictive welfare models, where farms intervene before conditions worsen. Wearables and biometric sensors complement this by continuously monitoring vital signs. AI-powered digital twins, virtual replicas of individual cows, simulate responses to environmental and management changes, enabling proactive decision-making. In nutrition science, platforms like those developed by the Beijing Institute of Animal Husbandry generate optimized feed profiles based on species, age, health status, and production goals, reducing both costs and environmental impact (Can, 2024). Smart feeders dynamically adjust rations in response to real-time animal data, while alerts for feed anomalies aid in the early detection of gastrointestinal disorders.

At a broader scale, AI supports epidemiological modeling, disease prediction, and veterinary public health. For instance, Akinsulie et al. (2024) highlighted AI's contribution to combating antimicrobial resistance, vaccine development, and zoonotic disease control. Tools like modular AI frameworks, using DL for object detection and identification, offer scalable, non-invasive welfare assessments across livestock sectors. These systems have been successfully deployed in dairy and swine farms to track welfare metrics in real time. In research by Ezanno et al. (2021), ML and Bayesian inference have enhanced genomic modeling, host-pathogen interaction analysis, and outbreak forecasting. Such tools support health surveillance and are critical in responding to global biosecurity challenges. AI also improves food safety and reduces waste through artificial intelligence in nutrition (AIN). Qian (2024) emphasized that AIN's integration into supply chains enhances contamination risk prediction, shelf-life management, and traceability, boosting both food security and consumer trust.

Finally, AI is redefining reproductive management, herd health, and diagnostics. Crowe et al. (2018) observed that modern farms now generate massive data streams, from fertility and milk yield to behavioral metrics, that AI can synthesize to optimize transition health and breeding efficiency. Embedded sensors in milking systems track somatic cell counts and hormone levels, enabling more accurate estrus detection and ovulation timing. AI tools also analyze movement and posture, offering automated, objective alternatives to manual welfare assessments. Fuentes et al. (2022) demonstrated that these tools scale across large operations, providing consistent, cost-effective monitoring. Veterinary diagnostics continue to evolve with AI-enhanced imaging, disease forecasting, and even robotic surgery. Ali and Al-Zu'bi (2023) noted the impact of these technologies on rapid diagnosis and individualized care. As Min et al. (2024) added, AI is now central to veterinary drug development and pathogen modeling, vital for production animals where early, affordable interventions are essential. In sum, AI and image processing are not just enhancing dairy and livestock systems; they are reshaping them into intelligent, sustainable, and ethical ecosystems for the future of agriculture.

## CHALLENGES WITH THE ADOPTION OF ARTIFICIAL INTELLIGENCE IN LIVESTOCK AND DAIRY FARMING

The integration of AI in livestock and dairy farming offers reformative potential but is hampered by numerous technical, economic, ethical, and infrastructural challenges. These barriers must be systematically understood to enable more widespread and effective adoption. A primary barrier is the high initial investment required for AI systems, encompassing hardware, software, infrastructure, and integration services. This burden disproportionately affects small and medium-scale farmers, who often lack access to capital. Ongoing operational and maintenance issues, such as power failures or battery malfunctions, further erode trust and usability.

Infrastructure gaps, especially in rural or developing regions, limit AI's effectiveness. Unreliable internet, inconsistent power supply, and inadequate computing resources hinder real-time data processing and system connectivity. Additionally, fragmented data from various sensors and platforms complicate integration and limit the usefulness of AI-powered decision-making systems. Data privacy, ownership, and security remain persistent concerns. Farmers may hesitate to share data due to fears of misuse or unauthorized access. Ensuring robust data governance and cybersecurity is essential to building user confidence. Compounding these issues are the technical challenges related to sensor accuracy, camera performance under barn conditions, and the computational demands of real-time AI systems.

Human capital and training gaps present further limitations. Many farmers and staff lack the technical skills required to operate, interpret, and maintain AI tools. The steep learning curve, limited dairy-specific education, and lack of user-friendly interfaces restrict widespread adoption (Jini et al., 2025; Kaushik et al., 2024). Poor data quality and inconsistency also undermine AI reliability. Variability in image resolution, inconsistent labeling, and non-standardized data inputs reduce model accuracy, particularly in health diagnostics. Traditional analytics struggle to manage the growing volume of big data, necessitating new methods for scalable, interpretable insights.

Many AI technologies remain confined to academic research, with limited real-world validation or commercial deployment. Inaccurate predictions, such as false positives in health alerts, can lead to skepticism among farmers. Additionally, cultural, ethical, and legal concerns, including job displacement, animal welfare objectification, and regulatory ambiguity, further hinder progress. AI systems are often designed for large-scale farms, leaving smallholders at a disadvantage. Regional differences in farming practices, breeds, and environmental conditions demand localized AI models, complicating scalability. Lastly, the lack of transparency in AI models, particularly black-box systems, reduces trust and decision-making utility on farms.

## A ROADMAP TO ARTIFICIAL INTELLIGENCE-DRIVEN DAIRY FARMING

The future of AI in dairy farming is poised to transform livestock management through smarter, more sustainable, and ethically sound practices. As AI technologies evolve, they promise to optimize precision feeding, behavior monitoring, and predictive diagnostics, enabling data-driven decisions tailored to both individual animals and entire farm operations. Integration of unified platforms, combining data from milking systems, feeding schedules, financial records, and sensors, will support holistic farm management and enhance operational resilience. To realize this potential, a multi-pronged roadmap is essential. First, inclusive AI adoption must be prioritized. Collaborative efforts among governments, academia, and the private sector can provide small and medium-scale farmers with access to digital infrastructure, training, and innovation hubs (Choyal, 2020). User-friendly interfaces and local language support will bridge digital divides, while modular, affordable solutions will democratize access to advanced tools (Jini et al., 2025).

Second, ethical and transparent AI governance is critical. Secure data handling, clear usage policies, and access control will build farmer trust. Emerging technologies like blockchain can ensure traceability and transparency across the dairy supply chain, promoting accountability and food safety. Third, interdisciplinary research and education should become foundational pillars. Cross-training in veterinary science, data analysis, animal behavior, and computer science will foster the development of practical and context-specific AI solutions. Integrating AI into veterinary and agricultural curricula will equip the next generation of professionals with essential skills for digital agriculture (Bao & Xie, 2022).

Fourth, next-generation innovations must be embedded in farm operations. Tools like generative AI-based virtual assistants, non-contact welfare monitoring using computer vision, drone-based surveillance, and renewable energy-powered sensors will reshape daily farm tasks. Predictive models combining GPS, accelerometer, and behavioral data will enable proactive animal health management and welfare assurance. Fifth, policy frameworks must guide equitable technology deployment. National strategies should promote standardization, interoperability, and farmer training while supporting ethical principles aligned with the One Health approach, recognizing the interconnectedness of human, animal, and environmental health (Neethirajan, 2023).

Lastly, AI's role must be to augment, not replace, human expertise. When implemented responsibly, AI can enhance dairy farming by improving reproduction, disease control, and sustainability. This roadmap calls for ethical, inclusive, and region-specific solutions supported by policies, training, and infrastructure. With transparency and collaboration, AI can drive a resilient, equitable, and future-ready dairy industry that safeguards animals and livelihoods (Jadhav et al., 2025).

## CONCLUSION

AI and ML are transforming dairy farming by reforming reproductive management, health monitoring, and overall farm efficiency. In estrus and gestation monitoring, AI enables early and precise detection of reproductive events, improving conception rates, reducing veterinary costs, and enhancing calf and maternal outcomes. Integrated with farm management systems, these tools provide real-time insights and data-driven recommendations, contributing to smarter breeding strategies and greater profitability. AI also plays a central role in early disease detection and personalized animal care. Technologies such as facial and gait analysis identify lameness and stress before clinical symptoms appear, enabling timely intervention and improving animal welfare. Precision feeding systems further enhance nutrition by tailoring diets based on individual needs, promoting sustainability, and reducing feed waste. The integration of computer vision and sensor data offers a non-invasive, accurate, and efficient alternative to traditional livestock monitoring methods. As these technologies mature and become more accessible, they are poised to address key challenges in dairy farming, including labor shortages, environmental impact, and ethical concerns. Despite hurdles like data privacy and system accessibility, the continued evolution of AI tools supports a future of dairy farming that is more sustainable, humane, and resilient. Embracing these innovations will be essential for navigating the demands of modern agriculture.

This review covered AI's transformative role in dairy farming, addressing health monitoring, precision feeding, reproduction, and sustainability. It synthesized global research on emerging technologies, highlighted operational benefits, and examined challenges, offering insights into advancing efficiency, welfare, and responsible innovation in dairy systems. It highlights progress in resource optimization, emphasizing that scalable deployment, inclusive policies, and farmer training are essential for ethical and resilient AI adoption in dairy farming.

## ABBREVIATIONS

AI	Artificial Intelligence
ML	Machine Learning
DL	Deep Learning
NLP	Natural Language Processing
CNN	Convolutional Neural Networks
RNNs	Recurrent Neural Networks
IoT	Internet of Things (IoT)

EC	Edge Computing
DLT	Distributed Ledger Technology
PLF	Precision Livestock Farming
PDF	Precision Dairy Farming
SVM	Support Vector Machines
XAI	Explainable AI
GIS	Geographic Information Systems
IA-DF	Integrated Approach to Dairy Farming
LSTMs	Long Short-Term Memory Networks
ANN	Artificial Neural Networks
PLS-DA	Partial Least Squares Discriminant Analysis
DSS	Decision Support Systems
KDD	Knowledge Discovery from Databases
IDSS	Intelligent Decision Support System
PPDM	Pregnancy Probability Diagnostic Model
FCE	Feed Conversion Efficiency
VR	Virtual Reality
SDGs	Sustainable Development Goals
KNN	K-Nearest Neighbors
BPNN	Back Propagation Neural Network
GA	Genetic Algorithm
SDF	Smart Dairy Farming
DFMS	Dairy Farm Management System
FACS	Facial Action Coding Systems
AIN	Artificial Intelligence in Nutrition

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## REFERENCES

- Aharwal, B., Roy, B., Meshram, S., & 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. <https://doi.org/10.18805/ag.D-5355>
- Akinsulie, O. C., Idris, I., Aliyu, V. A., Shahzad, S., Banwo, O. G., Ogunleye, S. C., Olorunshola, M., Okedoyin, D. O., Ugwu, C., Oladapo, I. P., & Gbadegoye, J. O. (2024). The potential application of artificial intelligence in veterinary clinical practice and biomedical research. *Frontiers in Veterinary Science*, 11. <https://doi.org/10.3389/fvets.2024.1347550>
- Albadrani, B. A., Abdel-Raheem, M. A., & Al-Farwachi, M. I. (2024). Artificial intelligence in veterinary care: A review of applications for animal health. *Egyptian Journal of Veterinary Sciences*, 55(6), 1725-1736. <https://doi.org/10.21608/ejvs.2024.260989.1769>
- Ali, A. 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. <https://doi.org/10.18805/IJAR.BF-1684>
- Ali, A. A., & Al-Zu'bi, M. (2023). Application of artificial intelligence in monitoring of animal health and welfare. *Indian Journal of Animal Research*, 57(11), 1550-1555. <https://doi.org/10.18805/IJAR.BF-1698>
- Alonso, R. S., Sittón-Candanedo, I., García, Ó., Prieto, J., & Rodríguez-González, S. (2020). An intelligent edge-IoT platform for monitoring livestock and crops in a dairy farming scenario. *Ad Hoc Networks*, 98, Article 102047. <https://doi.org/10.1016/j.adhoc.2019.102047>
- Amarnath, K. A., & Leelavathi, B. (2025). AI powered dairy farm management system. *International Research Journal of Modernization in Engineering Technology and Science*, 7, Article 04. [https://www.irjmets.com/uploadedfiles/paper//issue\\_4\\_april\\_2025/72500/final/fin\\_irjmets1744523146.pdf](https://www.irjmets.com/uploadedfiles/paper//issue_4_april_2025/72500/final/fin_irjmets1744523146.pdf)

- Balhara, S., Singh, R. P., & Ruhil, A. P. (2021). Data mining and decision support systems for efficient dairy production. *Veterinary World*, 14(5), Article 1258. <https://doi.org/10.14202/vetworld.2021.1258-1262>
- Bao, J., & Xie, Q. (2022). Artificial intelligence in animal farming: A systematic literature review. *Journal of Cleaner Production*, 331, Article 129956. <https://doi.org/10.1016/j.jclepro.2021.129956>
- Barracough, R., & Haskell, M. (2021). Use of advanced technology to enhance monitoring of dairy cow health. *Edinburgh Research Archive*. <https://era.ed.ac.uk/handle/1842/37972>
- Can, L. (2024). Application of artificial intelligence in animal nutrition and feed science. In *Proceedings of the 4<sup>th</sup> International Conference on Public Administration, Health and Humanity Development* (pp. 187-194). Atlantis Press. [https://doi.org/10.2991/978-2-38476-295-8\\_23](https://doi.org/10.2991/978-2-38476-295-8_23)
- Choyal, S. (2020). A study on the impact of artificial intelligence on Indian dairy industry. *International Journal of Novel Research and Development*, 5(8). <https://www.ijnrd.org/papers/IJNRD2008001.pdf>
- Connolly, A. (2024). Got AI? Valuable smart technology has arrived on the farm. *edairynews*. <https://en.edairynews.com/got-ai-valuable-smart-technology-has-arrived-on-the-farm/>
- Connolly, A. (2025). The rise of AI-powered smart cameras in dairy farming. *Dairy Herd*. <https://www.dairyherd.com/news/dairy-production/rise-ai-powered-smart-cameras-dairy-farming>
- Crowe, M. A., Hostens, M., & Opsomer, G. (2018). Reproductive management in dairy cows-the future. *Irish Veterinary Journal*, 71, 1-13. <https://doi.org/10.1186/s13620-017-0112-y>
- Dawkins, M. S. (2025). Smart farming and artificial intelligence (AI): How can we ensure that animal welfare is a priority? *Applied Animal Behaviour Science*, 283, Article 106519. <https://doi.org/10.1016/j.applanim.2025.106519>
- Dayoub, M., Shnaigat, S., Tarawneh, R. A., Al-Yacoub, A. N., Al-Barakeh, F., & Al-Najjar, K. (2024). Enhancing animal production through smart agriculture: Possibilities, hurdles, resolutions, and advantages. *Ruminants*, 4(1), 22-46. <https://doi.org/10.3390/ruminants4010003>
- de Castro, D. P., de Assis Diniz Sobrinho, F., Lima Junior, F. A., de Sousa Silva, T., e Silva, A. P. S., Nolêto, R. M. A., do Ó, A. O., de Oliveira, L. A., Barbosa, B. L., dos Santos de Moura, J., & da Silva Santos, N. P. (2025). Artificial intelligence applied to animal production. *Ciência Rural*, 55(7), Article e20230520. <https://doi.org/10.1590/0103-8478cr20230520>
- Dhaliwal, Y., Bi, H., & Neethirajan, S. (2025). Bimodal data analysis for early detection of lameness in dairy cows using artificial intelligence. *Journal of Agriculture and Food Research*, 21, Article 101837. <https://doi.org/10.1016/j.jafr.2025.101837>
- Dilaver, H., & Dilaver, K. F. (2024). Robotics systems and artificial intelligence applications in livestock farming. *Journal of Animal Science and Economics*, 3(2), 63-72. <https://doi.org/10.5281/zenodo.12518170>
- Dutt, T., Singh, M., Gaur, G. K., & Sahu, V. (2024). 'Artificial intelligence' as an intelligent tool for the future animal production and better management: A review. *Agricultural Reviews*, 45(2), 229-238. <https://doi.org/10.18805/ag-R-2297>
- Esquivel, S. Y. (2019). Artificial intelligence for livestock. *International Journal of Recent Research in Mathematics Computer Science and Information Technology*, 6(2), 1-3. <https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiW4MCnnNGNAXWavokEHQJMH0oQFnoECBoQAQ&url=https%3A%2F%2Fwww.paperpublications.org%2Fupload%2Fbook%2FArtificial%2520Intelligence%2520for%2520Livestock-1445.pdf&usg=AOvVaw0LsxCKCwBhOBvBykIZ-rMY&opi=89978449>
- Ezanno, P., Picault, S., Beaunée, G., Bailly, X., Muñoz, F., Duboz, R., Monod, H., & Guégan, J. F. (2021). Research perspectives on animal health in the era of artificial intelligence. *Veterinary Research*, 52, 1-15. <https://doi.org/10.1186/s13567-021-00902-4>
- Fuentes, S., Gonzalez Viejo, C., Cullen, B., Tongson, E., Chauhan, S. S., & Dunshea, F. R. (2020). Artificial intelligence applied to a robotic dairy farm to model milk productivity and quality based on cow data and daily environmental parameters. *Sensors*, 20(10), Article 2975. <https://doi.org/10.3390/s20102975>
- Fuentes, S., Viejo, C. G., Tongson, E., & Dunshea, F. R. (2022). The livestock farming digital transformation: Implementation of new and emerging technologies using artificial intelligence. *Animal Health Research Reviews*, 23(1), 59-71. <https://doi.org/10.1017/S1466252321000177>
- García, Á. (2025). Steering livestock production into the artificial intelligence age. *Dellait*. <https://dellait.com/steering-livestock-production-into-the-artificial-intelligence-age/>
- García-Méndez, S., de Arriba-Pérez, F., & Somoza-López, M. D. C. (2023). Informatics and dairy industry coalition: Artificial intelligence trends and present challenges. *IEEE Industrial Electronics Magazine*, 18(2), 30-37. <https://doi.org/10.1109/MIE.2023.3328106>
- Gulec, F. (2024). Harnessing the power of AI: Transforming dairy farms with advanced technologies. *LinkedIn*. <https://www.linkedin.com/pulse/harnessing-power-ai-transforming-dairy-farms-advanced-fatih-gulec-f5lqf>
- Gupta, S. (2024). AI applications in animal behavior analysis and welfare. In S. Gupta, W. Hasan, S. Singh, D. Kumar, M. J. Ansari, & S. Nisar (Eds.), *Agriculture 4.0* (pp. 224-244). CRC Press. <https://doi.org/10.1201/9781003570219-12>
- Hamadani, H., Hamadani, A., & Shabir, S. (2024). Artificial intelligence in animal farms for management and breeding. In A. Hamadani, N. A. Ganai, H. Henna, & J. Bashir (Eds.), *A biologist's guide to artificial intelligence* (pp. 167-182). Academic Press. <https://doi.org/10.1016/B978-0-443-24001-0.00011-7>
- Hamid, M., Mushtaq, N., Ahmad, H. I., & Haider, G. (2023). Use of artificial intelligence in assessing the livestock management. In H. I. Ahmad, & M. Hamid (Eds.), *Recent trends in livestock innovative technologies* (pp. 158-169). Bentham Science Publishers. <https://doi.org/10.2174/9789815165074123070014>

- Haribabu, G., Jothiperumal, N. G., Archangel, J. A., & Balasubramanian, M. (2025). Dairy cattle systems and economic analysis with smart technologies. In J. A. Archangel, S. Krishnan, & D. Dejeay (Eds.), *Smart technologies for sustainable livestock systems* (pp. 1-18). CRC Press. <https://doi.org/10.1201/9781003527114-1>
- Hossein-Zadeh, N. G. (2025). Artificial intelligence in veterinary and animal science: Applications, challenges, and future prospects. *Computers and Electronics in Agriculture*, 235, Article 110395. <https://doi.org/10.1016/j.compag.2025.110395>
- Jadhav, S. A., Kachhia, N. H., & Shah, V. (2025). The role of AI in production operation of dairy industry. *International Journal of Advanced Research in Science, Communication and Technology*, 5(3), 334-340. <https://doi.org/10.48175/IJARSC-25056>
- Jain, D. K., Sharma, A. K., & Ruhil, A. P. (2005). Role of information technology in dairy science: A review. *The Indian Journal of Animal Sciences*, 75(8), 985-991. <https://doi.org/10.33545/26174693.2025.v9.i1Sh.3565>
- Jini, D., Srishailam, B., Kumar, J., Alone, R. A., Bam, J., & Wangchu, L. (2025). Leveraging artificial intelligence (AI) for information dissemination and decision support in livestock husbandry. *International Journal of Advanced Biochemistry Research*, 9(1S), 570-574. <https://doi.org/10.33545/26174693.2025.v9.i1Sh.3565>
- Kashyap, N., & Deshmukh, B. (2023). Applying sensors and robotics towards smart animal management. In biotechnological interventions augmenting livestock health and production. In C. S. Mukhopadhyay, R. K. Choudhary, H. Panwar, & Y. S. Malik (Eds.), *Biotechnological interventions augmenting livestock health and production* (pp. 395-408). Springer. [https://doi.org/10.1007/978-981-99-2209-3\\_21](https://doi.org/10.1007/978-981-99-2209-3_21)
- Kassahun, A., Bloo, R., Catal, C., & Mishra, A. (2022). Dairy farm management information systems. *Electronics*, 11(2), Article 239. <https://doi.org/10.3390/electronics11020239>
- Kaushik, H., Rajwanshi, R., & Bhadauria, A. (2024). Modeling the challenges of technology adoption in dairy farming. *Journal of Science and Technology Policy Management*, 15(6), 1455-1480. <https://doi.org/10.1108/JSTPM-09-2022-0163>
- Krogstad, K., & Hartschuh, J. (2024). Progressive events: Technology, AI and the dairy industry at nutrition field day. *AGPROUD*. <https://www.agproud.com/articles/60718-progressive-events-technology-ai-and-the-dairy-industry-at-nutrition-field-day>
- Kurras, F., & Jakob, M. (2024). Smart dairy farming—The potential of the automatic monitoring of dairy cows' behaviour using a 360-degree camera. *Animals*, 14(4), Article 640. <https://doi.org/10.3390/ani14040640>
- Lima, L. M., Cavalcante, V. C., de Sousa, M. G., Fleury, C. A., Oliveira, D., & de Andrade Freitas, E. N. (2021). Artificial intelligence in support of welfare monitoring of dairy cattle: A systematic literature review. In *Proceedings of the 2021 International Conference on Computational Science and Computational Intelligence* (pp. 1708-1715). <https://doi.org/10.1109/CSCI54926.2021.00324>
- Lima-Campêlo, V. R., Paradis, M. E., Arango-Sabogal, J. C., Beauregard, N., Roy, J. P., Racicot, M., Aenishaenslin, C., & Dufour, S. (2024). Biosecurity adoption in Québec dairy farms: Results from a risk assessment questionnaire analyzed using conventional and unsupervised artificial intelligence methods. *Journal of Dairy Science*, 107(8), 6000-6014. <https://doi.org/10.3168/jds.2023-24256>
- Melak, A., Aseged, T., & Shitaw, T. (2024). The influence of artificial intelligence technology on the management of livestock farms. *International Journal of Distributed Sensor Networks*, (1), Article 8929748. <https://doi.org/10.1155/2024/8929748>
- Michielon, A., Litta, P., Bonelli, F., Don, G., Farisè, S., Giannuzzi, D., Milanese, M., Pietrucci, D., Vezzoli, A., Cecchinato, A., & Chillemi, G. (2024). Mind the step: An artificial intelligence-based monitoring platform for animal welfare. *Sensors*, 24(24), Article 8042. <https://doi.org/10.3390/s24248042>
- Micle, D. E., Deiac, F., Olar, A., Drența, R. F., Florean, C., Coman, I. G., & Arion, F. H. (2021). Research on innovative business plan. Smart cattle farming using artificial intelligent robotic process automation. *Agriculture*, 11(5), Article 430. <https://doi.org/10.3390/agriculture11050430>
- Min, P. K., Mito, K., & Kim, T. H. (2024). The evolving landscape of artificial intelligence applications in animal health. *Indian Journal of Animal Research*, 58(10), 1793-1798. <https://doi.org/10.18805/IJAR.BF-1742>
- Nadeau, J.-B. (2024). Artificial intelligence in the barn. *McGillREPORTER*. <https://reporter.mcgill.ca/artificial-intelligence-in-the-barn/>
- Nagahara, M., Tatemoto, S., Ito, T., Fujimoto, O., Ono, T., Taniguchi, M., Takagi, M., & Otoi, T. (2024). Designing a diagnostic method to predict the optimal artificial insemination timing in cows using artificial intelligence. *Frontiers in Animal Science*, 5. <https://doi.org/10.3389/fanim.2024.1399434>
- Neulai-Valeanu, A. S., Sanduleanu, C., & Porosnicu, I. (2025). From tradition to precision: Leveraging digital tools to improve cattle health and welfare. *Frontiers in Veterinary Science*, 12. <https://doi.org/10.3389/fvets.2025.1549512>
- Neethirajan, S. (2023). The significance and ethics of digital livestock farming. *AgriEngineering*, 5(1), 488-505. <https://doi.org/10.3390/agriengineering5010032>
- Neethirajan, S. (2022). Affective state recognition in livestock—Artificial intelligence approaches. *Animals*, 12(6), Article 759. <https://doi.org/10.20944/preprints202202.0074.v1>
- Nleya, S. M., & Ndlovu, S. (2022). Smart dairy farming overview: Innovation, algorithms and challenges. In A. Choudhury, A. Biswas, T. P. Singh, & S. K. Ghosh (Eds.), *Smart agriculture automation using advanced technologies. Transactions on computer systems and networks* (pp. 35-59). Springer. [https://doi.org/10.1007/978-981-16-6124-2\\_3](https://doi.org/10.1007/978-981-16-6124-2_3)
- Nogoy, K. M. C., Park, J., Chon, S. I., Sivamani, S., Park, M. J., Cho, J. P., Hong, H. K., Lee, D. H., & Choi, S. H. (2021). Precision detection of real-time conditions of dairy cows using an advanced artificial intelligence hub. *Applied Sciences*, 11(24), Article 12043. <https://doi.org/10.3390/app112412043>

- Pakrashi, A., Wallace, D., Mac Namee, B., Greene, D., & Guéret, C. (2023). CowMesh: A data-mesh architecture to unify dairy industry data for prediction and monitoring. *Frontiers in Artificial Intelligence*, 6. <https://doi.org/10.3389/frai.2023.1209507>
- Pandey, D. R., & Mishra, N. (2024). An integrated approach to dairy farming: AI and IoT-enabled monitoring of cows and crops via a mobile application. *BIO Web of Conferences*, 82, Article 05020. <https://doi.org/10.1051/bioconf/20248205020>
- Patel, H., Samad, A., Hamza, M., Muazzam, A., & Harahap, M. K. (2022). Role of artificial intelligence in livestock and poultry farming. *Sinkron: Jurnal dan Penelitian Teknik Informatika*, 6(4), 2425-2429. <https://doi.org/10.33395/sinkron.v7i4.11837>
- Pathak, A., & Rathore, A. (2023). Dairy and artificial intelligence: Enhancing efficiency and productivity. *Just Agriculture*, 3, 90-104. <https://justagriculture.in/files/newsletter/2023/august/17.%20Dairy%20and%20Artificial%20Intelligence-%20Enhancing%20Efficiency%20and%20Productivity.pdf>
- Priyashantha, H., & Vidanaratchi, J. K. (2024). Advancements in dairy research: Exploring nutritional strategies, enhancing raw milk quality and innovations—Unveiling the topic “new insights into Milk 2.0”. *Animals*, 14(13), Article 1870. <https://doi.org/10.3390/ani14131870>
- Qian, L. (2024). How can artificial intelligence help improve dairy quality control and reduce waste and loss? A glimpse into the future. *LinkedIn*. <https://www.linkedin.com/pulse/how-can-artificial-intelligence-help-improve-dairy-quality-control-mu0jc/>
- Rajagopal, A. R., Kumar, P., Choudhury, D., & Archangel, J. A. (2025). Automated tracking of individual cattle within a group. In J. A. Archangel, S. Krishnan, & D. Deje (Eds.), *Smart technologies for sustainable livestock systems* (pp. 105-123). CRC Press. <https://doi.org/10.1201/9781003527114-7>
- Schuetz, C. G., Schausberger, S., & Schrefl, M. (2018). Building an active semantic data warehouse for precision dairy farming. *Journal of Organizational Computing and Electronic Commerce*, 28(2), 122-141. <https://doi.org/10.1080/10919392.2018.1444344>
- Siachos, N., Neary, J. M., Smith, R. F., & Oikonomou, G. (2024). Automated dairy cattle lameness detection utilizing the power of artificial intelligence; current status quo and future research opportunities. *The Veterinary Journal*, 304, Article 106091. <https://doi.org/10.1016/j.tvjl.2024.106091>
- Singh, A. K., Bhakat, C., Ghosh, M. K., & Dutta, T. K. (2021). Technologies used at advanced dairy farms for optimizing the performance of dairy animals: A review. *Spanish Journal of Agricultural Research*, 19(4), Article 6. <https://doi.org/10.5424/sjar/2021194-17801>
- Sugiono, S., Soenoko, R., & Andriani, D. P. (2016). Analysis the relationship of physiological, environmental, and cow milk productivity using AI. In *Proceedings of the 2016 International Conference on Data and Software Engineering* (pp. 1-6). <https://doi.org/10.1109/ICODSE.2016.7936165>
- Thangavel, S. K., Somasundaram, K., & Ramasamy, M. (2025). Enhancing milk yield forecasting in dairy farming using an interpretable machine learning framework. In *Proceedings of the 2025 4<sup>th</sup> International Conference on Sentiment Analysis and Deep Learning* (pp. 1549-1557). <https://doi.org/10.1109/ICSADL65848.2025.10933035>
- Vargas-Bello-Pérez, E., Espinoza-Sandoval, O. R., Gonzalez Ronquillo, M., Angeles Hernandez, J. C., Chay-Canul, A. J., Lee-Rangel, H. A., Amaya, G. D., Keim, J. P., Baudracco, J., Mendonça Vieira, R. A., & Ghavipanje, N. (2024). The role of artificial intelligence in Latin American ruminant production systems. *Animal Frontiers*, 14(6), 23-32. <https://doi.org/10.1093/af/vfae034>
- Veeneman, D. (2025). AI and dairy farming. *AGPROUD*. <https://www.agproud.com/articles/60845-ai-and-dairy-farming>
- Vlaicu, P. A., Gras, M. A., Untea, A. E., Lefter, N. A., & Rotar, M. C. (2024). Advancing livestock technology: Intelligent systemization for enhanced productivity, welfare, and sustainability. *AgriEngineering*, 6(2), 1479-1496. <https://doi.org/10.3390/agriengineering6020084>
- Vyas, P., Ghosh, S., Roy, M., & Sharma, A. (2022). Machine learning applications in dairy farm management. In J. Singh, & A. Vyas (Eds.), *Advances in dairy microbial products* (pp. 385-396). Woodhead Publishing. <https://doi.org/10.1016/B978-0-323-85793-2.00006-0>
- Zhang, L., Guo, W., Lv, C., Guo, M., Yang, M., Fu, Q., & Liu, X. (2024). Advancements in artificial intelligence technology for improving animal welfare: Current applications and research progress. *Animal Research and One Health*, 2(1), 93-109. <https://doi.org/10.1002/aro2.44>