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TRENDS AND FUTURE DIRECTIONS OF ARTIFICIAL INTELLIGENCE APPLICATIONS IN IRANIAN LIVESTOCK PRODUCTION SYSTEMS – A REVIEW

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Abstract

In recent years, the global quest for livestock intensification driven by ever-increasing demands for animal food products raised concerns about animal welfare, environmental sustainability, and public health. Leveraging artificial intelligence (AI) technologies such as remote sensing, Internet of things (IoT), computer vision, and data-driven modeling has become a hotspot in livestock farming that could facilitate animal monitoring, disease detection, feed optimization, and health management. This review includes an assessment of these topics and research done in Iran so far, proposing future steps for the deployment of AI-powered technologies in farm applications. The Iranian livestock sector already seeing benefits from AI advancements and information technologies, however, most studies focused on model development without applications or deployment for the industry. Significant work is needed to address the limitations and challenges namely lack of data, economic feasibility, ethical concerns, infrastructure issues, and regulatory frameworks. Furthermore, reported AI-based methods and approaches have some inconsistencies in Iran that hinder validation. Looking forward, AI could create a new era in the livestock sector of Iran that not only copes with upcoming challenges but also boosts the circular economy making this country a pioneer in the region. However, tackling some potential limitations accompanying AI application in the Iranian livestock sector warrants the multi-disciplinary collaboration of veterinarians, computer scientists, animal nutritionists, agri-engineers, and governmental organizations.

Key words: artificial intelligence, smart farming, livestock, Iran, sustainability

Global food production faces critical challenges, largely attributed to the interplay of population growth and climatic change (FAO, 2021; Oliveira and Silva, 2023). The worldwide animal inventory pattern shows a decline in both quantity and quality of natural resources, posing a risk to global food security, especially given the needs generated by the ever-increasing human population (Salas et al., 2022; Neethirajan, 2020). Concurrently, the livestock sector encounters issues related to environmental footprint and animal welfare (Melak et al., 2024). Hence, this sector will have undertaken innovative solutions like artificial intelligence (AI) to address these challenges while protecting the environment and delivering high-quality products (Oliveira and Silva, 2023).

Tracing back to human civilization, the agriculture and livestock sector first relied on a labor force that future gave way to combustion engines, complemented by agrochemicals with the advent of the industrial revolution. These are followed by the integration of modern technologies like sensors, geolocators, and software for optimizing agriculture and livestock production (Dayoub et al., 2024; De Vries et al., 2023). Today, state-of-the-art technologies, such as the Internet of things (IoT), big data, cloud computing, and AI, play roles at the forefront of sustainable livestock production (Dayoub et al., 2024).

AI, a subfield of computer science, aims to empower computers or computer-controlled robots to acquire learning and evaluation faculties imitating living organisms. The term "AI" denotes either a specific technological branch or encompasses related fields like machine learning and deep learning, collectively outperforming traditional techniques in terms of precision (Neethirajan, 2020, 2023 c). Herein, we utilize "AI" in the latter manner, referring to the entirety of technology within this field. Integrating AI within the livestock sector offers creative solutions to various challenges encountered by farmers and industry in an animal-friendly and eco-friendly manner. Globally, major advancements over the last decade including automated feeding machinery, milking robots, and manure management have greatly facilitated real-time animal monitoring, data analytics, and decision-making that not only could maximize the quantity and quality of products but also reduce the reliance on human labor (Morrone et al., 2022; Neethirajan, 2023 b; Dayoub et al., 2024). Besides the scientific research, the application of sensor technologies (Neethirajan, 2023 b), machine learning (Neethirajan, 2020), deep learning (Oliveira et al., 2021), data-driven models (Ellis et al., 2020), precision livestock farming (Morrone et al., 2022), mathematical modeling (Tedeschi, 2022), and IoT (Zhang et al., 2021) for livestock production has been extensively reviewed.

In Iran, the livestock sector with over 16 million tons of animal products is one of the backbones of the agricultural economy employing 70% of the total agricultural workforce and generating 40% of the agricultural gross domestic product (GDP). Moreover, it provides close to 1.3 billion jobs, signifying its colossal role in supporting socioeconomic stability and growth (Ministry of Agriculture Jihad, 2020). However, water and land scarcity have created a crisis in Iran, pushing livestock producers to maximize production while utilizing minimum resources that further fuel incentives for academia, industry, and the market (Rezvani et al., 2022). To achieve long-term sustained livestock production in Iran, aligning with global tendencies is indispensable. This paper brings insights into how the implementation of AI technologies currently drives the livestock sector in Iran and what direction it will take in the future by reviewing the existing literature on AI applications in animal farming in this region. Despite falling behind pioneering countries embracing AI in livestock industries, Iran calls for academic collaboration to bridge prevailing technological gaps alongside the industrial sector. Focusing below are several key aspects wherein AI impacts Iran's livestock farming. Summarized findings aim to guide prioritized agendas in upcoming research and entrepreneurship initiatives, ultimately shaping targeted policy blueprints advocating AI adoption in Iran.

Livestock sector in Iran

Since the 2nd century BC, Iran stood as a central trading post along the historic Silk Road, driving commercial activity and serving as a platform for intellectual discourse between Eastern and Western civilizations. Today, ranking one of the largest countries in the world, Iran remains ripe with untapped global market potential (ICCIMA, 2023). Agriculture is a major economic sector in Iran, with a great potential for development. Since about 90% of the country's food requirements are met by domestic production, it has a huge share in the country's GDP (11.6%) as well as total employment (18%). The livestock sector in Iran engages more than 50% of rural inhabitants, generates ~80% of their income, contributes to 31.8% of the gross value of agricultural production, and forms a core element of Iranian diets (Ministry of Agriculture Jihad, 2020). Over the past four years, livestock production grew annually by 1.7%. Official data of 2021 indicated that total production of chicken meat, egg, red meat, cow milk, and aquaculture products reached 2.641, 1.081, 0.884, 11.20, and 1.210 million metric tons, respectively (ICCIMA, 2023).

Global evolution of AI

The development of AI began in the 1950s, initiated by notable scientists from the UK and USA, including Alan Turing, creator of the Turing Machine, while his cryptography works significantly impacted the Second World War (Turing, 1950). In 1956, the Dartmouth Conference marked the official field start of AI, with efforts of computer scientists, especially John McCarthy, Marvin Minsky, and Claude Shannon (McCarthy et al., 2006). AI research expanded globally throughout the subsequent decades, reaching European and Asian institutions. In the following decades AI faced various stages of optimism and doubt. Initial promise fueled investments and progress in AI programming languages (Lisp, Prolog), Expert Systems, and Knowledge-Based Systems. Japan initiated a program in the 1980s focused on developing intelligent machines using Logic and Prolog (Cantú-Ortiz et al., 2020). The 1990s brought renewed attention to the connectionist approach after advancements in artificial neural networks (ANN), fuzzy reasoning, data-driven modeling, and soft computing techniques addressing issues like speech recognition, computer vision, and sensory interactions (Das et al., 2019). By the new millennium, deep learning methods enabled widespread adoption of AI across multiple industries and applications. Governments, businesses, and everyday life now utilize AI extensively, emphasizing human-computer interaction and integrating with broader objectives such as Industry 4.0 (Cantú-Ortiz et al., 2020). Figure 1 displays a timeline of the milestones in the development of modern AI since its inception in the early 1930s.

AI application in livestock production in Iran

Globally, AI leverage marked the onset of a new era of efficient livestock farming underscored by mounting AI-powered research and developments (Dayoub et al., 2024; Fuentes, 2022; Tedeschi et al., 2021). Mirroring this global wave, in Iran research using AI in livestock currently covers a range of topics including predictive analytical models, health enhancement, and environmental monitoring and sustainability. Below we provide a quick look at AI applications in Iranian livestock systems.

Current AI practices, opportunities, and research trends

The following section presents an overview of the current AI practices, opportunities, and research trajectories in Iranian livestock systems. Table 1 provides a concise summary of the scholarly endeavors categorized into three parts: (i) prediction and modeling applications, (ii) detection and monitoring applications, and (iii) miscellaneous applications.

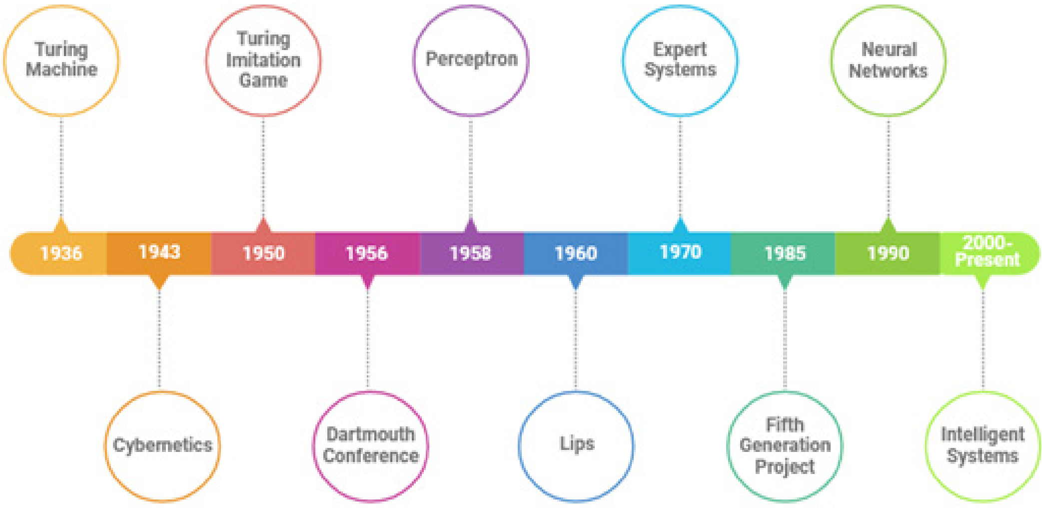

Figure 1. A timeline of key milestones in artificial intelligence (created with BioRender)

Animal nutrition: AI revolutionized livestock nutrition, offering practical applications like AI-driven feeding systems calculating precise, tailored feed quantities based on individual animals' distinct nutritional demands. Masoudi and Rouhani (2013) proposed an automated feeding delivery system for precise livestock dietary management. This system is equipped with sensors and microcontrollers that enable quantifying and recording of consumed diet, contributing to informed dietary management decisions. Shirzadifar et al. (2023) also developed a machine-learning algorithm to predict the most efficient feeding in beef cattle. Customized plans minimize waste, prevent overfeeding/underfeeding risks and optimize growth, and well-being could be achieved with AI-powered technologies.

Environmental monitoring: Implementing AI-driven environmental monitoring systems entails sensor technology and data analysis to continuously assess these conditions. In Iran, automatically adjusted ventilation, heating, or cooling preserve a favorable habitat, enhancing welfare and reducing diseases (Masoudi, 2016). AI algorithms were employed to monitor nitrate concentrations in dairy farms (Mohammadpour et al., 2024). In another study, Hosseinzadeh-Bandbafha et al. (2017) developed AI-based models for monitoring the energy output and greenhouse gas emissions in Iranian fattening farms.

Robots, equipment, and machinery: Along with the intensified livestock farming in Iran, especially over the past two decades, robotics and machinery have been successfully developed in the livestock sector including automated milking and feeding systems, ventilation and fogging equipment, and automated cleaning and disinfection systems, surveillance cameras, identification, and monitoring systems of workers (Masoudi, 2016). Interestingly, farmers are becoming interested in these AI-derived practices, foreseen to instigate a paradigm shift in the field. Kianmehr et al. (2013) devised a discriminating feed managerial tool allowing individualized feeding of cows supported by Radio Frequency Identification (RFID) technology and automated gateway controls.

Disease detection: AI technology has emerged as a powerful tool for animal disease prediction and monitoring. Applying data-driven modeling and machine learning algorithms, AI-powered systems could analyze big datasets of animal health, genetic information, and environmental conditions enabling early disease detection (Aharwal et al., 2023; Ezanno et al., 2021; Oliveira et al., 2021). At present, Iranian AI research gravitates heavily towards the development of machine learning and deep learning models engineered for early disease detection. Examples of AI-tailored models successfully applied in cattle include prediction of abortion (Keshavarzi et al., 2020); calving difficulty (Avizheh et al., 2023); parasitic infection rate (Meshgi et al., 2024); dystocia in dairy cows (Montazeri-Najafabadi et al., 2021); and brucellosis incidence rate (Bagheri et al., 2020), besides predictive models extended to cover influenza and Newcastle disease (Sadeghi et al., 2023) (Table 1). Recently, Sotoudeh et al. (2024) have developed an online livestock health monitoring system in Iran by leveraging available information and exploring new methods based on the IoT, ANN, and AI.

Table 1. Application of AI-based technologies in Iranian livestock systems

Applied technology	Parameter of interest	Short description	Accuracy of method	Reference
1	2	3	4	5
Category (i) Prediction and modeling applications				
Machine-learning (ML) algorithms	Prediction of abortion incidence in Iranian dairy herds	Predict abortion incidence using cow history records and bull genetic information available at 6 large commercial dairy farms with cows calved between 2005 and 2014	Accuracy of models ranged from 82.2% to 85.7%	Keshavarzi et al. (2020)
Machine-learning (ML) algorithms	Modeling the output energies of broiler farms	Combining the response surface method (RSM) and genetic algorithm (GA) for modeling the output energies using data from 210 broiler farms	R2 ranged from 87.95 to 96.50	Amini et al. (2020)
Machine-learning (ML) algorithms	Predicting milk price	Application of artificial neural networks (ANN) in predicting price of milk in Iran using data from 2006 to 2013	R2 = 0.90 RMSE=1849.90	Shahriary and Mir (2016)
Machine-learning (ML) algorithms	Predicting calving difficulty in Holstein cows	Predict calving difficulty in Iranian dairy herds with ML algorithms using historical data of cows that calved between 2011 and 2021 on two commercial dairy farms	F-measure = 0.367 to 0.406 Area under the curve (AUC) = 0.677 to 0.685	Avizheh et al. (2023)
Machine-learning (ML) algorithms	Predicting lamb, beef, and poultry meat market	Using hybrid algorithms (MLPANN-GA, MLPANN-PSO, and MLPANN-ICA) for modeling monthly prices of beef, lamb and chicken from 2001 to 2021	Not reported	Heydari (2023)
Machine-learning (ML) algorithms	Prediction of breeding values for milk production	Predict the breeding values for milk production traits in Iranian Holstein cows using 35,167 recorded between 1998 to 2009.	R = 0.836 RMSE = 0.08	Hamidi et al. (2017)
Computer vision	Prediction of body weight of Sistani cows	Using computer vision artificial neural network to predict the body weight of Sistani cows	R2 = 0.974	Khojastehkey et al. (2022)
Image processing and machine learning	Prediction of body weight of lambs	Image processing and artificial neural network to predict lamb's body weight using data from 115 newborn Zandi lambs	R2 = 0.974	Khojastehkey et al. (2016)
Machine-learning (ML) algorithms	Prediction of lactation curve	Using artificial neural networks and some mathematical functions in predicting lactation curve of Iranian dairy cows using 1,085,525 milk test day records during 1983–2012	R2 ranged from 0.992 to 0.996	Azizi et al. (2024)
Machine-learning (ML) algorithms	Modeling of energy ratio	Development of artificial neural networks to model energy ratio index using data from 40 broiler production farms in Iran	R2 = 0.974 RMSE = 0.0018 MAE = 0.0337	Kalhor et al. (2016)
Machine-learning (ML) algorithms	Estimated breeding values (EBV) of Iranian dairy cattle	Developing artificial neural networks and neuro-fuzzy systems, to estimate breeding values (EBV) of Iranian dairy cattle	R ranged from 0.92 to 0.93	Shahinfar et al. (2012)
Machine-learning (ML) algorithms	Genetic prediction of buffalo	Using support vector machine (SVM), random forest (RF), and discriminate analysis principal component (DAPC) to predict population structure and genetics of buffalo in Iran.	ACU ranged from 80% to 96%	Azizi et al. (2020)

Table 1. – contd.

1	2	3	4	5
Category (ii) Detection and monitoring applications				
Machine-learning (ML) algorithms	Calving interval	Find the association between productive and reproductive traits with calving interval using data of 15,465 cows between 1990 and 2011	R2 = 0.992	Ghaderi et al. (2016)
Thermal-image processing and machine learning.	Early detection of avian diseases	Early detection of avian influenza and Newcastle disease for 14-day-old broilers based on thermal-image processing and machine learning.	Accuracy = 97.22%	Sadeghi et al. (2023)
Sound signals and machine-learning (ML) algorithms	Nutritional behavior of dairy cattle	Classifying chewing and rumination in dairy cows using sound signals and machine learning	Total precision = 89.62% to 95.9%	Abdanan Mehdizadeh et al. (2023)
Data mining	Dystocia in Iranian dairy cows	Application of data mining to determine the factors affecting dystocia in dairy cattle using the total records of 413,205 cows	R = 88.11% to 98.80 RMSE = 0.053 to 0.075	Montazeri-Najafabadi et al. (2021)
Data mining	Forecasting brucellosis incidence rate	Development of an artificial neural network and support vector machine to forecast the monthly incidence rate of brucellosis in Iran using time series and data mining from 2010 to 2019	R2 = 0.990 MAE = 0.175 MARE = 0.007	Bagheri et al. (2020)
Sound technologies and machine-learning (ML) algorithms	Livestock health monitoring system	Monitoring livestock health by exploring new methods based on the Internet of things, artificial neural networks, and artificial intelligence	Not reported	Sotoudeh et al. (2024)
Machine-learning (ML) algorithms	Prediction brucellosis disease	Prediction and diagnosis of livestock with brucellosis disease using neural network algorithm and decision tree	Accuracy ranged from 90.2% to 96.7%	Gholami and Javidan (2017)
Machine-learning (ML) algorithms	Gastrointestinal nematodes	Multi-scale habitat modeling framework for predicting the potential distribution of sheep gastrointestinal nematodes in Iran with a MaxEnt machine learning algorithm	Not reported	Meshgi et al. (2024)
Machine-learning (ML) algorithms	Describing weight gain of sheep	Development of a neural network model to describe the weight gain of sheep from genes polymorphism, birth weight and birth type	R2 = 0.92	Tahmoorespur and Ahmadi (2012)
Machine-learning (ML) algorithms	Lameness scoring	Develop an automated lameness scoring system comparable with conventional subjective lameness scoring using artificial neural networks	Not reported	Ghotoorlar et al. (2012)
Machine-learning (ML) algorithms	Dairy cow locomotion score	Develop artificial neural networks to investigate the relationship between locomotion score and production traits using a total number of 123 dairy cows from a free-stall housing	R2 = 0.80 RMSE = 0.16	Norouzian et al. (2021)
Fuzzy logic	Dairy cattle judging	Development of a fuzzy expert system for handling the qualitative terms and variables for judging dairy cattle	Not reported	Alizadeh et al. (2008)

Table 1. – contd.

1	2	3	4	5
Category (iii) Miscellaneous applications				
Image processing and machine learning	Pelt pattern classification of lambs	Classification of pelt pattern in newborn Zandi lambs using image processing and neural network with data of 300 animals.	Total accuracy = 92%	Khojastehkey et al. (2015)
Image processing and machine learning	Curl size and pelt color determination	Using image processing and the artificial neural network determine the pelt color and curl size of newborn lambs using data from 300 new-born Zandi sheep	$R2 = 0.984$	Khojastehkey et al. (2019)
Machine-learning (ML) algorithms	Energy output of dairy farms	Development of artificial neural network model to assess the energy input-output prediction in dairy farms of Iran. Data used were culled from 50 randomly selected farms In Iran.	$R2 = 0.88$ RMSE = 0.015	Sefeedpari et al. (2013)
Machine-learning (ML) algorithms	Emissions from livestock manure	Develop the multi-layer perceptron (MLP) and radial basis function (RBF) models, to accurately forecast the production of livestock and poultry manure from 2020 to 2030	Not reported	Vaysi et al. (2023)

Challenges of AI application

The leveraging of Big Data and AI has revolutionized livestock production, empowering farmers to easily monitor animals and environmental conditions to achieve improved efficiency, enhanced sustainability, and pioneering management strategies (Lovarelli et al., 2020; Morrone et al., 2022). However, there are still several unknowns, limitations, and open-ended questions in AI adoption in the field of animal science. Below, we summarized several potential disadvantages and challenges associated with AI application in Iran setting:

Costs and economic considerations: costs and economic issues seem to pose the most significant barriers to the implementation of AI technologies in the livestock sector worldwide (Georgopoulos et al., 2023). Regarding AI technology adoption in Iran's animal systems, major financial burdens including initial investment costs and ongoing maintenance expenses, costs of training technological experts, and costs of updating/upgrading AI technologies, form part of the overall cost-benefit analysis conducted by stakeholders. It has been reported that small-scale farming in Iran makes the application of cutting-edge technologies and AI uneconomical for farmers (Bagherpour and Mohamadi, 2014). The absence of clear evidence of financial benefits accruing from employing AI technologies in farm settings serves as an additional barrier to their extensive adoption in Iran (Rezvani et al., 2022).

Knowledge and model complexity: technical know-how (knowledge of optimal hardware and software options, installation of tools, and usage of these technologies) represents a crucial factor in implementing AI technologies in livestock farms. In Iran, despite the presence, setup, and functionality of some AI-based technologies in intense large farms, the insufficient awareness about the operation, alongside novelty-related complexities, tends to inhibit numerous stakeholders, especially small-scale farms, from accepting new technologies (Taheri et al., 2022; Rezvani et al., 2022).

Data collection and quality: to apply mechanistic models in animal farming, we need to collect a large volume of diverse datasets. Some of them may include local weather data, air quality data, voice signals of animals, visual data of various animal movements, and other such animal behavior data. Various sensors can help us capture real-time data effectively. But, such a system will need to store large volumes of textual, audio, and video data. Storing and processing such vast amounts of data, every day, throughout the year is not possible with an ordinary computer and it will soon run out of storage and computing power. It has been well established that the limited technology exposure and reliance on traditional conventions in Iran's small-scale agribusinesses create substantial obstacles to systematic data collection (Bagherpour and Mohamadi, 2014).

Digital divide and obsolescence: "Digital divide" refers to unequal access to and utilization of digital technologies within certain populations due to diverse factors like education level and technical proficiency. Additionally, pervasive technological obsolescence further exacerbates inequity. Technological tools are typically regarded as becoming outdated every 5.2 years (Ignatova, 2020). Hence, obsolescence creates disparities between those adepts at navigating rapid changes and those struggling to maintain pace.

Ethics and privacy considerations: the application of AI-driven approaches in the livestock sector generates extensive datasets, engendering notable challenges linked to data security and privacy. Orandi et al. (2020) pointed out that the absence of clearly specified rights and ownership over collected data acts as a major barrier to IoT development in Iran. It has been also shown that privacy and data protection constitute critical challenges threatening digitization in Iran (Rezvani et al., 2022). So, the advancement of AI-powered systems in the Iranian livestock sector guaranteeing safekeeping mechanisms and transmissions remains critical to prevent unauthorized access and the misuse of data.

Regulatory and legal frameworks: Integrating AI within Iran's livestock farming requires the development of regulatory blueprints and legislative constructs to manage deployments and handle attendant ethical issues. Ardekani et al. (2017) reported that decreased agricultural subsidies, caused by intentional government interference in Iran, have narrowed incentives for the domestic farming sector. Also, Taheri et al. (2022) acknowledged that low encouragement and minimal governmental subsidizing support act as major drawbacks preventing successful digital transformation within the Iranian agricultural domain. The similarities and overlaps of numerous and different institutions and tasks with parallelism, the overlap of activities, and the lack of integration in policy-making are other regulatory roadblocks disrupting development of the AI in Iran (Rezvani et al., 2022). Therefore, policymakers and stakeholders will need to collaborate to establish legal frameworks and regulations, ensuring responsible development of AI in livestock production while safeguarding animal welfare, farmer livelihoods, and consumer interests.

Future directions and needs gaps

AI-powered technologies are up-and-coming and will result in a substantial shift in the livestock sector (Fuentes et al., 2022; Dayoub et al., 2024; Melak et al., 2024). Global leverage of these novel technologies could enhance decision-making, improve animal welfare, and boost production efficiency. The future directions of AI in livestock sector include developments of sensor technology (wearable and environmental sensors) (Tedeschi et al., 2021), computer vision and imaging technologies (Oliveira et al., 2021; Neethirajan and Kemp, 2021 a), drones and unmanned aerial vehicles (UAVs) (Alanezi et al., 2022), IoT (Chaudhry et al., 2020; Neethirajan, 2023 b), and advancements in AI algorithms (Ellis et al., 2020; De Vries et al., 2023). Besides, blockchain technology, a decentralized encryption ledger, organizes transactions into interconnected "blocks", and emerges as an efficient tool to integrate records, traceability from farm-to-table, and effective disease outbreak tracking (Neethirajan and Kemp, 2021 b). Digital Twins, a digital replica of a real-world that simulates the physical state, biological state, and condition of the real-world entity based on input data, that could predict, optimize, and improve livestock production, is another AI direction for animal farming (Neethirajan and Kemp, 2021 b). Micro-innovations, small improvements, and/or adaptations made to existing technologies, are also becoming a hotspot (Charatsari et al., 2022; Neethirajan, 2023 c). The metaverse, a virtual world comprising a collective virtual shared space where users interact with one another through avatars and computer-generated objects, aims to mirror the real-world, also projected as a promising area for future animal farming (Neethirajan, 2023 a).

The leverage of AI in livestock systems in Iran, although lagging behind global trends is still full of potential and promise. Some technological tools have been not only well developed in Iran's animal production setting but also well accepted by farmers and stakeholders. The academic sector in this country is also aligned with global tendencies displaying a pronounced trajectory of growth and enhancement.

Most AI discoveries and developments for Iran's livestock systems primarily inhabit the academic realm, and practical deployments are neglected. Iran's diverse climatic conditions, variable feed quality, and unique animal husbandry practices necessitate tailored AI solutions. The lack of quantitative data to support AI's efficacy in this sector hinders progress. Moreover, the limited pilot trials and insufficient cost-benefit analyses render these technologies less attractive for Iranian farmers, especially in small-scale production setting. The absence of ethical and social considerations in AI's implementation in Iranian livestock production warrants attention. Potential job displacement and the need for workforce skill shifts could adversely affect communities dependent on conventional farming, necessitating a careful examination of social impacts. Technological infrastructure issues, i.e. limitations in connectivity in Iran's rural areas, also could impede AI solutions.

Hence, to change this, future AI research should be based on realistic problems in the livestock industry and thorough economic analysis, emphasizing their beneficial impact. The next step is to develop affordable AI-based solutions, starting with predictive analytics from historical data. The initial idea lies in deploying AI in areas with available data, targeting maximized performance. In parallel, "friendly" software and effective marketing techniques encourage greater AI adoption among farmers.

Looking ahead, future endeavors to contribute to this field should be focused on tackling the identified challenges in this review. An example of this is to establish strategies aimed at minimizing the costs of AI-powered technologies within the livestock sector, particularly for small farmers.

Additionally, the development of tailored training programs for farmers, empowering them with the necessary skills and knowledge about AI-based technology is crucial. Executing cost-benefit assessments detailing the long-term and large-scale impact of AI to create benchmarks in Iran's livestock setting is also required. Collaboration on policy recommendations fosters supportive regulatory frameworks backing AI adoption in Iranian animal husbandry. Authorities ought to emphasize provision and instruction regarding digital equipment for all involved parties. Collaborative efforts involving academia, government entities, and technology developers can facilitate the dissemination of user-friendly digital solutions tailored to diverse farm sizes and individual skill levels. Moreover, designing adaptable, regularly updated tools that remain cost-efficient and locally accessible helps counteract the effects of accelerated obsolescence. Implementing these measures ensures sustainable progression towards bridging the AI gap in Iran's animal agriculture. These efforts seek to render AI-powered technologies more affordable, easily adopted, and impactful for shifting Iran's livestock production toward long-term sustainability, enquiring about collaborative endeavors from researchers, policymakers, and stakeholders to overcome existing barriers and foster widespread adoption.

Conclusion

Meeting the ever-increasing demand for animal-derived food amidst challenges such as climate change, land degradation, and animal welfare underscores the significance of sustainable modern livestock management practices. AI-based technologies have shown great potential in addressing these issues in an eco-friendly and animal-friendly manner. The leverage of AI in livestock systems in Iran, although lagging behind the global trends is still full of potential and promise. Limited testing, ethical concerns, infrastructure and regulatory issues as well as the lack of cost-benefit evaluations in Iran make AI technologies undesirable for farmers. Ensuring AI research should concentrate on refining assessment indicators, supported by rigorous and factual financial examinations accentuating positive effects. Simultaneously, deploying user-friendly design features and shrewd marketing campaigns shall facilitate broader technology acceptance among Iranian farmers. Collaborative efforts involving academia, government entities, and technology developers can facilitate the dissemination of user-friendly digital solutions tailored to diverse farm sizes and individual skill levels in Iran's livestock setting.

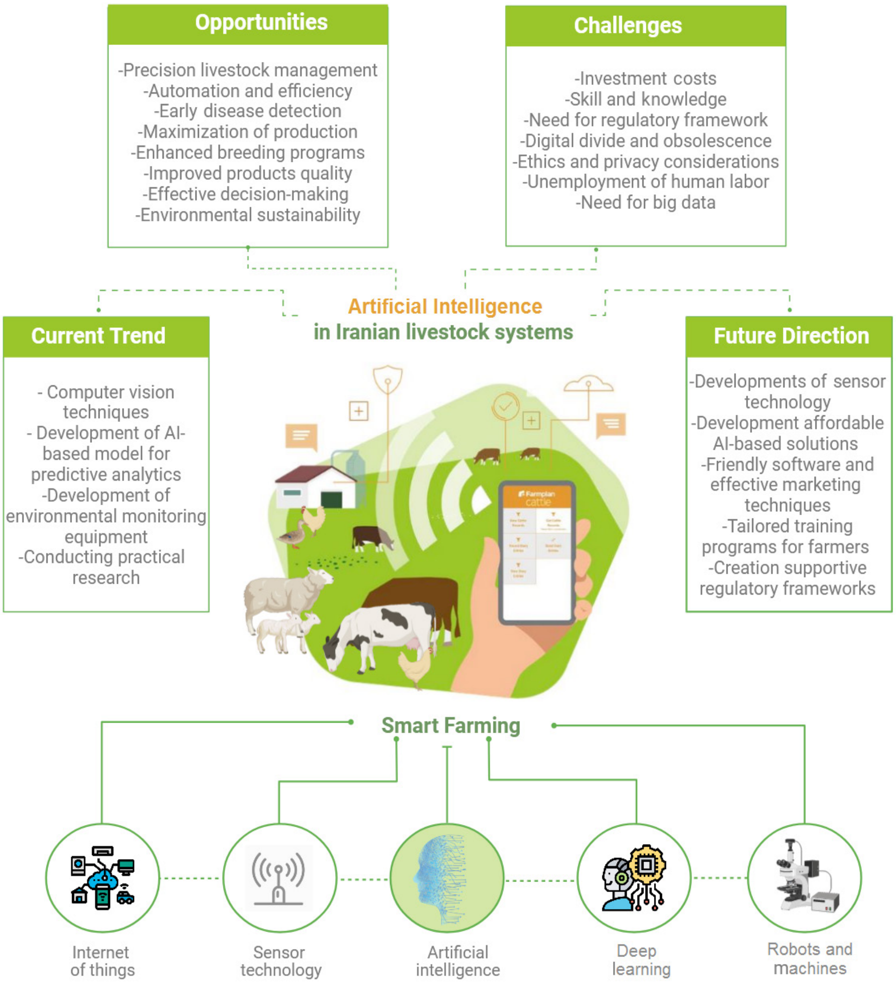

Figure 2. A quick look at AI applications in Iranian livestock systems (created with BioRender)

Conflicts of interest

The authors declare that there are no conflicts of interest to declare and there has been no significant financial support for this work that could have influenced its outcome.

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Data availability statement

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

Authors contributions

Navid Ghavipanje (N.G.): conceptualization, writing – preparing the original draft; writing – review and editing; visualization. Mohammad Hassan Fathi Nasri (M.H.F.N.): writing – review and editing. Einar Vargas-Bello-Pérez (E.V.B.P.): conceptualization; writing – review and editing.

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