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Dairy farming in the era of artificial intelligence: trend or a real game changer?

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Abstract

Artificial Intelligence (AI) is reshaping the world as we know it, impacting all aspects of modern society, basically due to the advances in computer power, data availability and AI algorithms. The dairy sector is also on the move, from the exponential growth in AI research, to ready to use AI-based products, this new evolution to Dairy 4.0 represents a potential 'game-changer' for the dairy sector, to confront challenges regarding sustainability, welfare, and profitability. This research reflection explores the possible impact of AI, discusses the main drivers in the field and describes its origins, challenges, and opportunities. Further, we present a multidimensional vision considering factors that are not commonly considered in dairy research, such as geopolitical aspects and legal regulations that can have an impact on the application of AI in the dairy sector. This is just the beginning of the third tide of AI, and a future is still ahead. For now, the current advances in AI at on-farm level seem limited and based on the revised data, we believe that AI can be a 'game-changer' only if it is integrated with other components of Dairy 4.0 (such as robotics) and is fully adopted by dairy farmers.

Throughout its history, humanity has experienced several industrial revolutions that have transformed the way we live, and dairy farms have adapted and taken advantage of these technological advances, incorporating them into their production processes. Today, with the arrival of the Fourth Industrial Revolution (4IR), the dairy sector is adapting these technologies to the new concept of Dairy 4.0, and one of the most promising of those technologies is AI (Hassoun *et al*., 2023). Since the 1950s, AI has gone through several periods of low and high development, but in recent years it has gained unprecedented strength. At the macro level of innovation systems, the big tech companies such as Open AI, Meta AI or Google AI, have been leading the AI research at a basic level due to their infrastructure. Beyond this, an increasing number of national Governments consider AI to be a key technology and investing heavily in time and money.

The first scientific reports implementing AI related to dairy science appeared in the mid-1990s (see for example, Nielen *et al*., 1995) and have grown exponentially since the mid-2010s. Although there are great advances in the AI sector, its use in the dairy sector will depend on the feasibility of the technology being applied on-farm, especially when one considers the challenges around data integration and the technical capabilities of farmers. Regarding data integration, Knight (2020) suggested that continuous big-data collection from different sensors for cloud storage could be divided into '*at cow*' (examples are data from accelerometers, temperature, heart rate and pH analysis), '*near cow*' (video and sound recordings, climate data, feed analysis and GPS) and '*from cow*' (milk, blood, hair, DNA, and faeces).

The dairy sector faces important sustainability challenges in the coming decades, but the question of what impact AI could have on these challenges remains unclear. Due to the current trends in AI in all aspects of society, this Research Reflection will discuss whether AI could be considered a 'game-changer' for the dairy sector. To explore this possibility, we used a multidimensional view, examining the origins of AI through to the current available on-farm applications and including current challenges and opportunities. A '*game-changer*' in global terms, comprises those events and developments that shape the course of history (Avelino *et al.*, 2017). Now, several studies have been published in other areas such as health, economics, and education, but for dairy science, this concept has not been coined and thus, AI has not been catalogued as a 'game-changer'. Although we focus on AI, other pillars of Dairy 4.0 will also be considered due to their importance and their vital coexistence with AI.

The fourth industrial revolution and Dairy 4.0

Since the early 21st century, the world has been immersed in the fourth industrial revolution (4IR), a term developed by Klaus Schwab, during the World Economic Forum Annual Meeting 2016. The term Industry 4.0 originated from a German project designed to stimulate the high-tech industry between 2011 and 2015 (Philbeck and Davis, 2019). Several adaptations to these terms have been proposed to identify agri-food areas, such as Agriculture 4.0, Precision Agriculture, Dairy 4.0, Smart-Farming, Smart Dairies and Precision Livestock Farming. Hassoun *et al.* (2023) suggested that the main pillars of Dairy 4.0 are AI, big data, robotics, 3D printing, internet of things (IoT) and blockchain (enabling the provision of real-time data of milk as a farm to fork entity, to ensure transparency and food security; Gehlot *et al.*, 2022). However, other 4IR technologies are also important including simulation, quantum computing, augmented reality, and cloud computing as well as horizontal and vertical integration.

Today's leading Dairy 4.0 technologies, which have been in the market for several years, include automated milking systems (robotic milking systems not requiring the direct assistance of milking staff), animal monitoring systems (such as neck collars for heat detection, health and behavioural monitoring sensors, eating pattern monitoring devices, calving alerts, etc.), automatic feed dispensers, robotic feed pushers and cleaners, milk quality and mastitis detection systems, turn-key systems designed to measure greenhouse gas emissions (CH_4 and CO_2) and other technologies based largely on sensors (Knight, 2020; Krpalkova *et al.*, 2021). The main benefits of implementing the 4IR are increased efficiency and productivity, revenue gain and reduced human/manual errors (Neethirajan, 2020; Jerhamre *et al.*, 2022).

Artificial intelligence: origins and framework

The origins of modern AI can be traced back to the 1950s when pioneers in computer science were exploring whether computers could be able to think. So, AI can be defined as a simulation of human intelligence (replicated by a system or a machine to perceive their environment, learn and make decisions), but until now a conclusive definition has not been established and several proposals remain under debate (Wang, 2019; Hassoun *et al.*, 2023). In recent years, there has been a rapid growth in technological advancements such as computer power, with large availability of data ('big data') allowing AI to evolve from mere theory to real-world applications on an unprecedented scale (Topol, 2019). The framework of AI is organized into different layers according to Xu *et al.* (2021):

- Infrastructure layer (data, machine and deep learning algorithms, storage, and computing power).
- Perception layer (computer vision, speech recognition, and synthesis) that allows machines to see and hear.
- Cognitive layer (natural language processing) provides superior capabilities of induction and reasoning.
- Decision-making layer (expert systems and automatic planning) allows AI to make complex decisions such as interpretation, diagnosis, and prediction.

Periods of AI technological development

Over time, the field of AI has passed through several periods of ups and downs in knowledge development, commonly known as seasons, divided into tides of summers (ups) and winters (downs: Toosi *et al.*, 2021). The first winter occurred from 1973 to 1980 and the second from 1987 to 1993 (Haenlein and Kaplan, 2019). The main reasons for the first winter were the disappointments in machine translation and the consequent Lighthill report for the British Science Research Council with the conclusion that the expectations of AI development projects were exaggerated. Consequently, the UK cut funding to AI, and other agencies like DARPA (Defense Advanced Research Projects Agency) redirected the funding to more applied AI projects. Although the possibility of the sector of AI going through another winter is possible, at the same time the chances are probably slimmer than before because of the large financial investment of big tech companies in the sector, as well as the governmental support which now sees the potential of AI to provide financial growth in many industries and enhance military capabilities. At the end of the second winter, the first publications on dairy-related AI started to appear and grow exponentially (Nielen *et al.*, 1995; Hassoun *et al.*, 2023). As shown in Fig. 1, this is explained by the achievements of the third summer of AI, and this trend is not expected to stop.

The fundamentals of machine learning, deep learning and computer vision

Machine learning (ML) systems are classified according to the amount and type of supervision during training. Four major categories exist, namely supervised learning, unsupervised learning, semisupervised learning and reinforcement learning. The most used algorithms in supervised learning are k-nearest neighbours (KNN), support vector machines (SVM), decision trees and random forest. For example, the module for Python Scikit-learn contains a vast variety of ML algorithms. Another example is Weka, which also contains a wide variety of ML algorithms with the advantage that it can be used without writing any program code by using a graphical user interface, making it attractive for new students in AI.

Deep learning (DL) a subset of ML, deals with deep neural networks (DNN) inspired by the biological neural networks in the human brain. The term DL was introduced in 2006 to describe the training, by eliminating gradient vanishing, of an algorithm capable of recognizing handwritten digits with a precision of more than 98% (Le Cun *et al.*, 2015). After this breakthrough, DL became the most researched field in AI, achieving important technological advances such as voice and facial recognition and the creation of autonomous vehicles. In the early stages of DL, the process of developing artificial neural networks (ANN) was only possible with a few tools, like MATLAB, OpenNN and Torch, that required high computer capabilities and tedious procedures. Today, with availability and free access to modern frameworks like TensorFlow developed by the Google Brain Team, CNTK by Microsoft Research, Pytorch based on Torch, MXNet

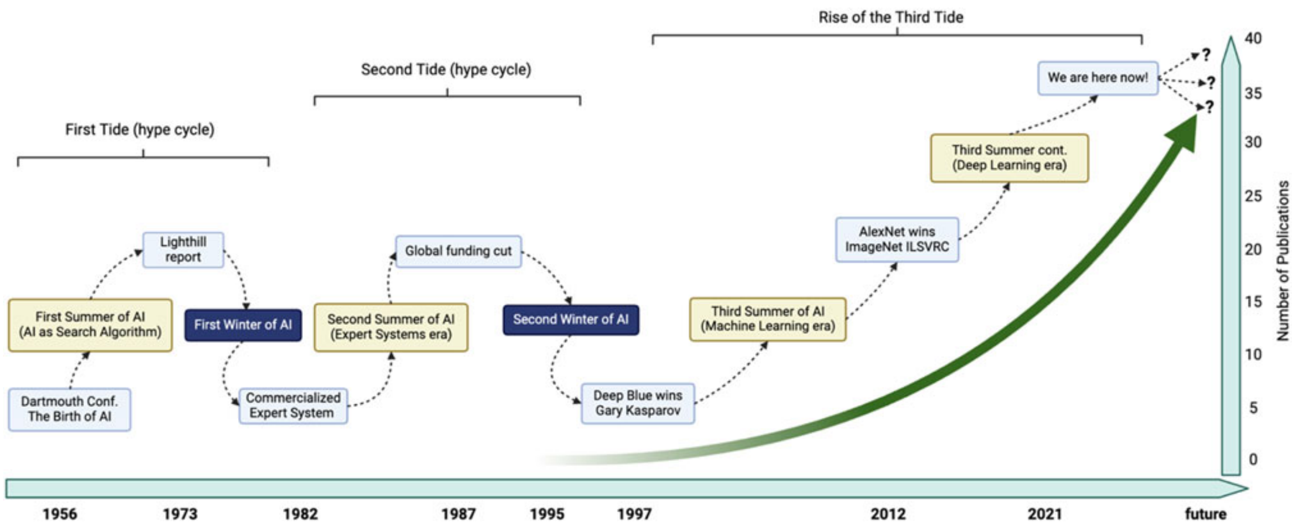

Figure 1. Cycles of development in the field of AI and the number of publications (green arrow) in dairy (Toosi *et al.*, 2021; Hassoun *et al.*, 2023).

by Amazon, Keras and ONNX by the Linux Foundation for example, the application of these methods has become simpler (Xu *et al.*, 2021). There is a wide range of artificial/deep learning networks (ANN, DNN) including convolutional neural networks (CNNs), recurrent neural networks (RNNs) and long short-term memory (LSTM), as well as the recent development of liquid neural networks (LNN).

The origins of computer vision (CV) can be traced back to the 1960s, with the first attempts to imitate human vision by sensory mimics (cameras) and cognitive system mimics (machine perception). The common pipeline of CV starts with the image or video acquisition, followed by image preprocessing which prepares the data for analysis and concludes with standardization, colour transformation, binarization and thresholding. Fernandez *et al.* (2020) presented a complete overview of the current applications of CV in the field of animal science. Traditional CV techniques like scale invariant feature transform or speed up robust features are usually combined with ML algorithms (SVM, KNN). DL can be defined as a tool to enable CV, and their combination has achieved enormous progress (O'Mahony *et al.*, 2020).

Examples of machine learning, deep learning and computer vision in livestock farming

An example of the use of ML is demonstrated by Chen *et al.* (2022), where they compare several ML algorithms to predict the excretion of nitrogen in the manure of dairy cows. The use of ML in precision livestock farming was reviewed by Garcia *et al.* (2020). A systematic literature review (Cockburn, 2020) of the application of ML models in cattle farming confirms that ML has the potential to become a ubiquitous tool in various aspects of dairy farming, particularly to predict data with the most used models including SVM, KNN, and artificial neural networks (ANNs). However, most tested algorithms have yet to be refined for practical use. A review (Mahmud *et al.*, 2021) on the current state of DL in cattle highlighted two main DL algorithms: combining image processing and DL and fine-tuning pre-trained DL models. The main challenges associated with DL in the dairy sector include image quality, data processing speed, dataset size, redundant information, and cattle movement during data acquisition. We anticipate increased interest in automated cattle farming using cutting-edge DL models while acknowledging their real-time implementation requires addressing the current challenges and further improvements.

Recent CV system adoption in livestock applications has shown promising results, demonstrating their potential for high-throughput phenotyping. These systems offer real-time, non-invasive, and precise predictions for health, welfare, nutrition and reproduction at both group and individual levels (Fernandez *et al.*, 2020; Oliveira *et al.*, 2021). CV applications are a burgeoning topic in dairy farming and some commercial products are already on the market. Nevertheless, there are still hurdles that must be overcome through continued research to create independent solutions that can provide vital information.

Innovation systems: application pathways of AI at the farm level

To fully obtain the main opportunities and advantages coming from day-to-day application of AI on the dairy farm, several actions need to allow the natural coevolution of science, technology and production. This will depend on the innovative systems that vary among countries but usually interact between them as proposed by Pugliese *et al.* (2019) in a multilayered space of innovation activities. The conceptual framework of the national innovation systems suggests that the main goal of the research is innovation (Fig. 2). The first step depends on the knowledge infrastructure that is composed of three research sectors: university, government, and industry. The second step is transforming knowledge into utility, by established companies or new startups, taking the knowledge, and transforming it into applied technologies. The introduction of a new product or service into the market interacts with customers as the third step. Usually, these types of companies are transnational conglomerates that are searching for profits on a new product of interest (Sena *et al.*, 2021).

Geopolitical implications of AI

Several countries have classified AI as a matter of national security, mainly due to the potential impact of AI on the military,

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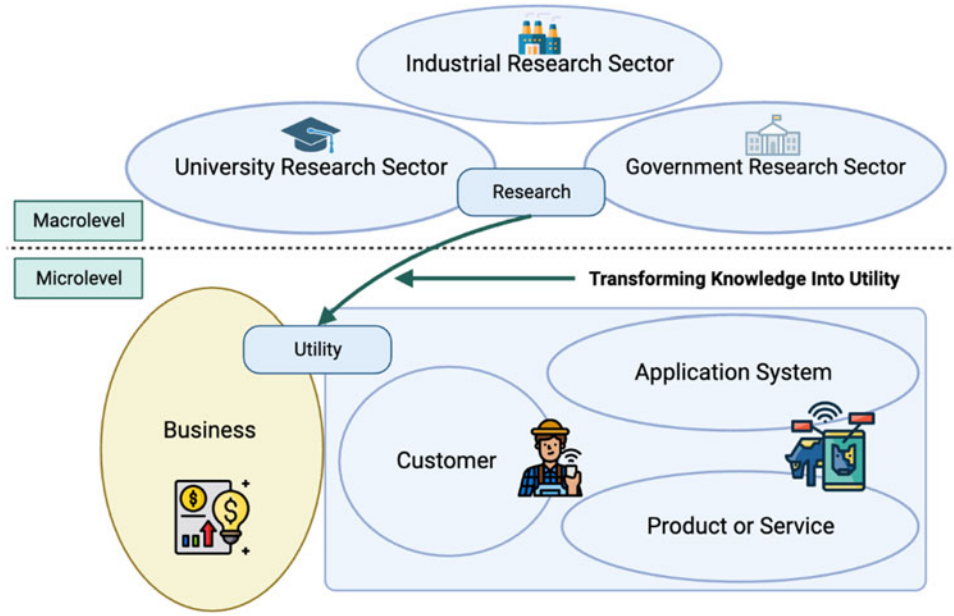

Figure 2. Components of the Innovative Systems, adapted from Betz *et al*. (2016).

cybersecurity, and economics. It is estimated that the global investment in AI could reach $200 billion by 2025 which is almost double the $94 billion invested in 2021 (Goldman Sachs, 2023). Two countries are leading the technological race in AI, China, and the United States. China introduced the 'Next Generation AI Development Plan' in 2017 intending to become the global AI innovation centre. Based on Freeman's hypothesis, Lundvall and Rikap (2022), suggested that the emergence of a radically new technology like AI could reconfigure the world order, and explored in depth how crucial AI is for China. The EU also launched its initiative 'AI for Europe' in 2018, intending to become a world leader in this technology. The US in 2018 created the 'National Security Commission on Artificial Intelligence' to evaluate their status in the field of IA, with the conclusion that the US is not prepared to defend or compete in the era of AI. Also, other countries (like Japan, South Korea, India, Israel, Singapore, and Taiwan) have the intention of becoming leaders in the AI race (Schmidt *et al.*, 2021). This wave of interest in AI on a global scale not only benefits non-agri-food sectors but is also an opportunity for the expansion of AI on Dairy 4.0 through increased resources for research, followed by increased availability of potentially useful algorithms and tools capable of solving specific problems in the dairy industry. However, risks exist. One of these is over-reliance on one or a few companies and/or countries/regions for the provision of technology and materials for their construction, as experienced previously with semiconductors during the COVID-19 pandemic (Michael, 2023). Under this scenario some concerns need to be considered, such as how susceptible dairy farmers using AI will be in geopolitical conflicts and changes in the global control of the distribution of certain resources, for example, where data analysis is done on servers located outside their country.

Legal and ethical concerns related to AI

Although the field of AI had remained unregulated worldwide, the EU was the first to propose the 'AI Act' in 2021, reaching a political agreement in 2023, and on the way to becoming an EU law between 2024 and 2026 (Madiega and Chahri, 2023). These initiatives aim to classify and regulate the providers of AI, based on their risk, mainly to protect the consumer's rights (facial recognition in public spaces is an obvious example) and a special emphasis on generative AI (systems such as ChatGPT that create new content) related to transparency requirements. Also, the US president in 2023 issued an 'Executive order on the safe, secure and trustworthy development and use of AI'. These regulations aimed to allay concerns on fraud, discrimination, bias, and disinformation.

Although these initiatives have been issued, none of them contemplate the agri-food sector directly and it is still unclear how they will be implemented in non-agri-food sectors. De Baerdemaeker (2023) presented a study at the request of the European Parliament Parliamentary Research Services which describes the applications, risks and impacts on agri-food areas. The report identified AI as a key technology for modern agriculture, but among the concerns identified was clarification regarding the ownership and the exploitation of the data generated by sensors in farms, the potential risks of automation and robotics and measures to ensure that they are safe and secure for the animals and farmers. The report also proposed support for protecting the investment of farmers in AI technologies. It is likely that in the future the launch of new regulations may affect how AI is implemented on dairy farms (De Baerdemaeker, 2023).

Leading countries and trends in dairy AI research

In recent years there has been an exponential growth in the number of scientific publications dealing with AI and dairy cows. The first publications started to appear in the mid-90s (Nielen *et al.*, 1995). Several reviews have explored the geographic location, technologies employed, and areas of dairy science impacted (nutrition, reproduction, and health: Cockburn, 2020; Mahmud *et al.*, 2021; Shine and Murphy, 2022; Hassoun *et al.*, 2023). Of these four literature reviews, two trends in geographic locations

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were identified namely dominance of USA and Ireland and emergence of China. Other emerging regions include Australia, India, and the United Kingdom. The review of Shine and Murphy (2021) on AI and ML applications in dairy farming (literature between 1999 and 2021) showed an exponential increase in publications after 2010, mostly addressing physiology and health-related problems in dairy cows (32%) using data most often derived from sensors (48%). Also, since 2018 publications mostly employed neural network algorithms, suggesting an increasing use of DL algorithms in the dairy sector. AI techniques in the dairy sector were mainly applied to management, milk yield prediction and resource usage as well as health and physiological monitoring (including mastitis, body condition, metabolic status, lameness, heat stress, reproduction outcomes, dystocia and calving, and feeding (Cockburn, 2020; Garcia *et al*., 2020; Mahmud *et al*., 2021). The literature, however, noted that AI algorithms often failed to become reliably implemented in practice, mainly due to poor training data (Cockburn, 2020).

Robotics is also making its mark in dairy farming, the main example being voluntary milking systems that milk cows without being guided by humans, employing laser-guided detection of teat placement for attachment of the milking unit accomplished by algorithms that appear intelligent. Self-driving vehicles delivering feed have also become reality (De Vries *et al*., 2023). Virtual reality is another AI application in the dairy sector, employed (for example) for the training of farm workers and modelled on web-based virtual dairy herds to promote active learning of students and farmers as well as simulation and optimization models to support decision-making in dairy farms. Furthermore, video-based monitoring systems have been suggested as a potential solution for ensuring employee compliance with farm protocols, but inevitably such systems raise concerns among employees regarding punitive consequences, data security and confidentiality (De Vries *et al*., 2023). Of note, earlier studies of AI applications in dairy-related sectors lacked consistent reporting of model accuracy, performance, and scalability. Most focused solely on model development, neglecting real-world pilots or deployments. This makes it difficult to assess practicality and applicability, as models need continuous updating and adaptation to changing circumstances.

Challenges faced by dairy science researchers related to AI

One of the main challenges that confronts animal science researchers is that AI engineering is unlikely to be included in their training and skill development, requiring disciplines such as mathematics, statistics and computer programming and understanding of concepts such as big data, ML and DL. Consequently, research students need to quickly acquire these abilities if they are to be fully involved in all steps of an AI research project. This will often not be possible, hence collaborations with AI engineers or bioinformaticians for the programming process are essential. In turn, these individuals will need close guidance and monitoring to understand the interpretation of AI results into biological processes. Although multidisciplinary teams offer several benefits to scientific progress, early career students and researchers may lose their interest and motivation, as they might feel less ownership of their research programme and redirect their research interest to more traditional research areas such as reproduction or nutrition. This has led academic programmes to incorporate courses on the topics of AI and, on many occasions, hire specialized staff.

Dairy sector's major challenges

The global future of dairy farming faces major challenges, not least due to a growing population estimated to be 9.8 billion in 2050. In 2017, the total composition-standardized milk production from all dairy species reached 864 million tonnes, and it is estimated that in 2030 the demand will be 1,168 million tonnes, an increase of 35% in 13 years (Wyrzykowski *et al*., 2018). This raises the pressure on agri-food systems to increase productivity to cover the growing demand and ensure food security. At the same time, production systems are also required to adapt to the changing climate and play a key role in mitigation by reducing greenhouse gas emissions (agriculture contributes approximately 12% of the global emissions of GHG, whilst 30% of anthropogenic methane is estimated to come from ruminants: Wijerathna-Yapa and Pathirana, 2022). Creating a sustainable milk production system that guarantees food safety will require significant change.

Available AI-based Dairy 4.0 products

At the dairy farm level, the applicability of AI technologies is limited to the available products on the market, that have developed user-friendly interfaces (Fifield, 2020). The great majority of these products are in the field of CV. For example, Cattle Eye Ltd. (UK; Cattle Eye, 2023) is a commercially available technology that tracks body condition scores as well as lameness indicators. Another example is Alus Feedbunk Management from Ever.Ag Ltd, which allows the use of CV to monitor the feed bunk and inform the dairy farmer when supplementation of feed is needed (US; Cainthus, 2023). Regarding augmented reality, Nedap Livestock Management (NL; Nedap, 2023) offers a product that, through a virtual reality glass, allows the user to navigate through the records of individual cows and register daily actions, *via* holograms.

In the field of data-based technologies Dairy Data Warehouse has developed Predicta Guardian (NL; DDW, 2023), which recovers data from individual cows and sends it to the cloud for analysis through AI, purportedly to predict 60 d in advance the likelihood of transition diseases (ketosis, milk fever, displaced abomasum and retained placenta) and send an alert to the farmer to implement corrective actions. Another example is algoMilk (SP; algoMilk, 2023) which, using DL, integrates data from individual cows (such as body weight, lactation number and production) with feed ingredients costs, to present the best solution to group cows based on their nutritional needs and (financially) optimize the ration.

The major challenge limiting further progress is almost certainly the need to integrate data from multiple sources (Cabrera and Fadul-Pacheco, 2021). There is an understandable lack of clarity regarding the detailed of analysis algorithms as a result of manufacturers needing to protect their intellectual property. How this will be resolved is currently unclear.

Final remarks

This research reflection shows a multidimensional vision, from the origins and drivers of AI and the possible impact of geopolitical factors on AI research, through to actual applications in dairy systems and future expectations. We are enjoying the third summer of AI development, when new types of AI algorithms, especially in the field of DL, are constantly reported and updated. Most of the AI applications for livestock farming are currently

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academic with little implementation for real-world settings. To change this, multidisciplinary teams should prioritize the development of efficient and cost-effective technologies, beginning with the analysis of large datasets gathered from various dairy sectors.

The speed of AI technology development requires dairy scientists to acquire knowledge of technological tools, and the relevant skills to apply them at the dairy farm level. In the short term, the authors of this research reflection believe that AI can be a 'game-changer' only if AI is integrated with other components of Dairy 4.0 such as robotics and is fully adopted by dairy farmers. The biggest opportunities in the short- to mid-term are probably integrated tools based on DL and CV, rather than in decision support systems based on data and AI. This is due to challenges around data integration from multiple sensors. However, for now the acquisition and storage of data is the most developed aspect of dairy-sector AI. Farmers are limited to available AI products in the market, but more companies will be launching new ready-to-use AI-based products for dairy farmers within the next few years. The survival of these new startups in the early stages will be dependent on the performance of their products and their ability to co-develop together with dairy farmers so that they meet their requirements and gain their trust.

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