Towards White Revolution 2.0: Challenges and Opportunities for the Industry 4.0 Technologies in Indian Dairy Industry

Abstract

The world has encountered numerous global crises, including epidemics, military conflicts, and economic collapse. Innovative digital technologies such as Industry 4.0 (I4.0) can undoubtedly help improve industries' operations during critical times. The dairy industry has seen an increment in technological adoption in the last few years. Adopting cutting-edge technologies is regarded as more feasible as compared to existing practices. The advancements achieved through the white revolution became game changers for the Indian dairy industry, establishing it as a top producer. Following the present scenarios, the Indian dairy sector needs a new revolution that prioritizes improving safety, quality, transparency, and sustainability by employing digital technologies. This review critically demonstrates the emergence of technological transformations in the Indian dairy industry. We developed a conceptual framework for the concept introduced as "White Revolution 2.0", which indicates the digital revolution in the Indian dairy industry. This proposed framework presents three dimensions of "White Revolution 2.0", i.e., technological dimension, external factors, and applications of I4.0. The proposed framework will significantly improve dairy operations by effectively addressing the identified challenges throughout every aspect of the dairy industry. The findings indicate that adopting the proposed concept can ensure effective supply chain integration and a sustainable future for the dairy industry by integrating all stakeholders. Practical implementation of the proposed concept will surely improve food safety, security, and quality sustainably. This review will assist practitioners and researchers in understanding the fundamentals and necessity of the "White Revolution 2.0". The developed framework can serve as a roadmap for integrated dairy digitalization.

Keywords: Dairy Industry, Digitalization, Food Safety, Industry 4.0, Sustainability, White Revolution 2.0.

1. Introduction

The term "Industry 4.0" is derived from the German phrase "Industrie 4.0", which first appeared in 2011 at the Hannover trade fair handling (Schuh et al., 2016). The German government's high-tech strategy was to encourage technological innovations and digitalization of industrial operations. Robotics, simulation, integrated systems, big data (BD), Internet of Things (IoT), cloud computing, cyber security, augmented reality, and additive manufacturing were the initial pillars of I4.0. The primary goal of I4.0 technologies is to reduce production costs while increasing flexibility and agility through elevated production and quality improvements (Hassoun et al., 2022b). In the perishable food supply chain, it is critical to meet consumer demands considering the factors related to quality, cost, on-time distribution, and wastage. Food material handling is a crucial component of the supply chain (Fredriksson and Liljestrand 2015). It encompasses cold and ambient logistics, requiring precise planning, execution, and efficient monitoring to effectively manage the movement of food products from farm to fork (Hopkins and Hawking 2018). Production and distribution are experiencing transformations and their reliance on I4.0 technologies. For example, machines can anticipate and request service; operators trained on 3D simulators and fictional characters in augmented reality glasses can provide virtual service assistance (Monshizadeh et al., 2023). Industry 4.0 has the potential to revolutionize the food industry through innovative, integrated technology and web-based platforms. The dairy sector represents one of the largest and most significant agricultural sectors worldwide, offering humans an essential resource for nutrient intake (Hassoun et al., 2022b).

The dairy industry is still at the forefront of a technological transformation, with emerging technologies and technological advancements evolving in all aspects of the dairy sector's farming and production systems. Factors such as food safety and quality issues, animal welfare, increasing consumer demands, waste management, and optimization contribute to the dairy industry's requirement for technological innovations (McDonald et al. 2016). Notably, the worldwide population continues to grow rapidly, so consumer demand for dairy products is increasing. Thus, dairy producers must sustainably increase milk production and processed dairy products (Malik et al., 2023). Industry 4.0 and related technologies have been discussed for their potential to increase digitalization and automation, resulting in the vision of smart manufacturing with increased productivity, improved food quality, less waste, and optimized production in the dairy industry (Hassoun et al. 2022a). Additionally, many barriers posed by the COVID-19 pandemic, including labor shortages, quality and safety measures, logistics disruptions, reduced processing capacity, milk spoilage, etc., have made businesses think of digitalization and automation (Sarkar et al. 2020; Munien and Telukdarie 2021; Goodarzian et al. 2021). The applicability of I4.0 in the dairy industry is limited to animal welfare, automation, monitoring, etc. However, considering the current scenario, the dairy industry needs digital transformation employing I4.0 technologies in an integrated manner (Malik et al. 2023). Fig. 1 demonstrates a pictorial representation of digital technologies and their sub-parts. Layer 2 presents the I4.0 technologies and blockchain; layer 3 includes their major subtypes.

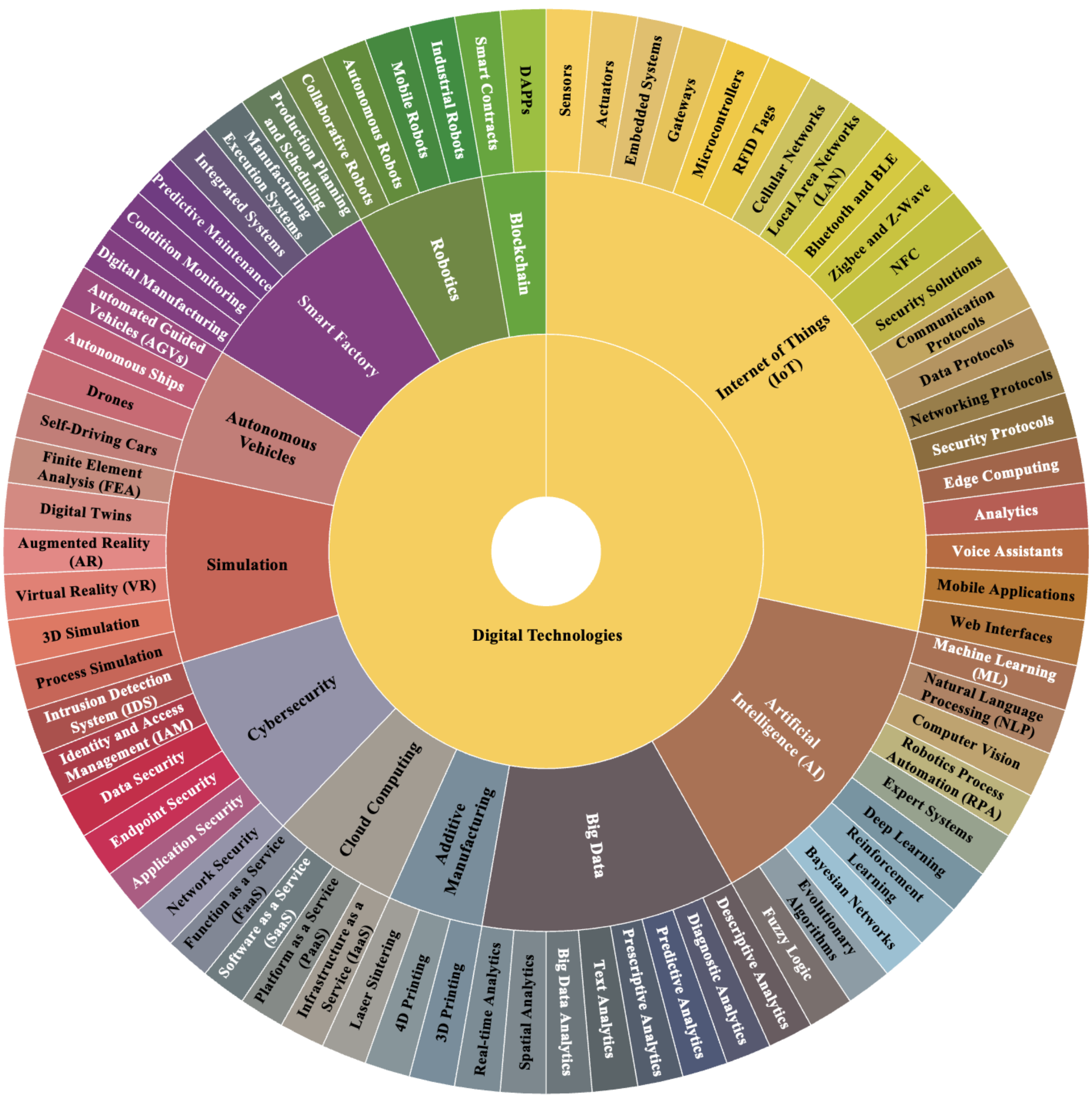

Fig. 1 Overview of Digital technologies

In line with the digital transformations, the term 'White Revolution 2.0' refers to technological advancements in farm-to-fork operations within the dairy industry, which could be considered under the digital revolution umbrella. In White Revolution 2.0, factors like industrial, human, and technology could deal with the critical challenges of the dairy industry. Accordingly, the dairy industry will benefit significantly from I4.0 and digitalization. Predictive maintenance could also help identify the indications for specific operational parameters and avoid unexpected breakdowns, thus improving overall business performance (Abidi et al. 2022; Bueno et al. 2023). Though several smart industries are presently implementing I4.0 technologies that enable them to operate in an increasingly competitive environment, the dairy industry must adopt this industrialization wave (Jachimczyk et al. 2021). Despite employing automation for some tasks such as milking, packaging, and handling, many operations within the dairy industry are not fully "digitalized", which could be due to the complicated structures. Many dairy producers still rely on historical data and accordingly plan their demands and production, making it challenging to foresee business growth and sales targets (Murphy et al. 2014; Shyian et al. 2021). Numerous dairy farms are currently facing significant delays and falling behind set schedules, and therefore, require support and assistance to meet the increasing consumer demand (Daftary 2019; Cabrera and Fadul-Pacheco 2021; Nurhayati et al. 2023).

Furthermore, COVID-19 has also accelerated developing and implementing cutting-edge technologies in production facilities across all areas. The larger players in the dairy industry have mostly adopted and capitalized upon these improvements. More inequalities in capability among large and small producers have resulted from these developments (Munien and Telukdarie 2021). There are hopeful prospects for small dairy industries despite the challenges. The profit margins of smaller dairies can be improved by several methods that do not drain resources or slow the production process. Developments and breakthroughs in automation and integration improve advances in food safety, quality, flexible production, reliability, and traceability (Maldonado-Siman et al. 2013).

The dairy industry is becoming increasingly sophisticated to achieve higher efficiency and flexibility. The emerging technologies that comprise I4.0 can help producers improve their workflow, operations, and maintenance. The dairy industry has adopted several technological applications based on the user interface as the primary application area. The interface focuses on real-world optimization applications in real-time and highly accurate data sharing in production by integrating information systems with process control (Akbar et al. 2020; Alonso et al. 2020). This paper focuses on current technological advancements and breakthroughs in the dairy industry, emphasizing I4.0 technology. This review is an extended work of the concept suggested by (Malik et al. 2023) in the context of dairy integration through a digital revolution. There is a lack of an integrated framework, especially in the dairy industry, that can incorporate or link dairy operations and stakeholders in an optimized way to enhance dairy functionality. Considering this as a gap, we proposed the "White Revolution 2.0" concept, which will provide a 360-degree approach to the dairy industry by addressing existing challenges. Hence, the main objectives of the review are the following:

(1) Analyze the current state of technological interventions in the dairy industry and provide an overview of dairy 4.0 technologies and enablers.

(2) Identify the enablers to develop the "White Revolution 2.0" concept for the dairy industry.

This article is structured as follows: Section 2 provides the literature review; Section 3 offers a brief introduction to the concept of "The White Revolution 2.0"; Section 4 gives a detailed overview of I4.0 technologies in the dairy industry. Section 5 highlights the need for "The White Revolution 2.0" in the dairy industry, along with recent milk adulteration and frauds occurring worldwide; Section 6 presents a discussion along with implications of the study; and finally, Section 7 concludes the review with future research directions.

2. Related Studies

The literature findings show that I4.0 technologies are functional in the dairy industry but at a low level; many studies reported the application of big data, automation, ML, and sensors in the dairy industry for animal welfare, quality control, analytics, etc. (Wilbey 2017; Hansen et al. 2020; Newton et al. 2020). The researchers proposed a framework based on I4.0 Technologies to achieve manufacturing sustainability for industries (Bag et al. 2021). Many researchers highlight the importance of technological intervention and its impact on the dairy industry in a sustainable direction (Basunathe et al. 2010; Upton et al. 2015; Cabrera and Fadul-Pacheco 2021). The researchers address the factors impacting technology adoption among farmers, showing that trust, collaboration, and awareness are the primary responsible factors (Akzar et al. 2022). The authors discussed current research trends related to the adoption of blockchain technology in supply chain activities and presented a brief overview of associated challenges and future research opportunities from business perspectives (Chakraborty et al. 2023). Some researchers focused on applying innovative technological solutions, including IoT and other digital technologies, as enablers to address the issues related to circular economy and supply chain sustainability (Akbari and Hopkins 2022; Jauhar et al. 2023). The Industry 5.0 concept to address disruptions in the supply chain was discussed by (Agrawal et al. 2023) through an integrated human collaboration approach and the impact of various disruptions such as climate issues, war, and pandemics. The supply chain 4.0 methods and the role of social media was discussed by (Hoang et al. 2023) using a systematic and bibliometric analysis to explore several aspects of supply chain 4.0.

For example, the data relevant to animal activities, such as feeding, rumination, sleeping, movement patterns, etc., can be evaluated, and health trends can be obtained (Fuentes et al. 2020). BD also helps with disease prevention and feeding issues. There is a significant opportunity to use BD to enhance the efficiency and productivity of the dairy industry (Neethirajan 2020). The sensor-based technology can identify animal sickness efficiently and accurately before it affects the milk supply. By collecting real-time cattle statistics like movement, temperature, and pulses, IoT acts as a vital platform for livestock farming (Vate-U-Lan et al. 2017). This critical data can be utilized for a comprehensive investigation to determine cow oestrus. The most exciting advantages of this method are a boost in milk production, dairy industry profitability, and lower labor and medical treatment expenses. It has also gained the interest of the dairy industry and animal welfare programs (Doinea et al. 2015; Tang et al. 2018; Michie et al. 2020). AR offers essential data about individual cattle, such as identity, health history, productivity, heat signs, feeding patterns, and inactive behavior, among other things (Jagtap et al. 2021). One of Asia's top retailers, the Dairy Farm Organization, was the target of a cyber-attack from the REvil group (Madsen 2021). The leading dairy company in the world, Lactalis, has reported being the victim of cybercrime. The company claims that only a few network systems were affected during the incident (Gatlan 2021). Consumers have more faith in the dairy industry because of blockchain's track-and-trace capabilities, ability to combat food fraud, immutable data, secure data storage, and increased security in the production process (Casino et al. 2020). Recent developments have greatly improved the incorporation of automation and monitoring of dairy operations in image processing technology (Huang et al. 2014). Dairy processing and manufacturing facilities employing automated systems must conform to the strict safety and quality guidelines of regulatory bodies that oversee the food industry. Dairy manufacturers face difficulty observing such processing operations and identifying how they affect the quality of the finished product. Image-processing techniques can be employed to thoroughly evaluate dairy products at every production stage. Imaging technologies have become widespread in the dairy industry for various essential purposes, including melamine detection, texture, and stability testing (Jarvis et al. 2017; Ebrahimnejad et al. 2018).

Based on the reviewed literature, Table 1 presents an overview of potential technologies applicable in the dairy industry. We identified the factors which can serve as a foundation for the proposed theoretical concept.

Table 1 Studies on the intervention of digital technologies in the dairy industry

As Table 1 shows, most of the studies reported research in a theoretical context, and very few highlighted the practicality of I4.0 in dairy operations. Some successful technological implementations in the dairy industry were also reported in the literature, which include animal health monitoring using ML (Franceschini et al. 2022), streamlining the dairy ecosystem by IoT and blockchain technology implementation (Gehlot et al. 2022); decision-making tools based on IoT and big data analytics (Cabrera et al. 2020), robotics-enabled automated milking system, etc. Food security worldwide is a pressing problem in a society with limited resources, evolving climate conditions, and a rapidly growing population. A future smart dairy industry requires extensive integration throughout the farm-factory interface (Augustin et al. 2013). The dairy industry must re-evaluate its resource consumption to remain competitive and productive to minimize the climate effects (Cabrera and Fadul-Pacheco 2021). Also, the evaluation of production-imposed variation in production, opportunities for on-farm processors, and the impact on in-plant operations is required to build a comprehensive approach for efficient and productive milk conversions into products in a sustainable manner. Concentrating on dairy farms can help improve sustainable development by optimizing transportation, chilling costs, and carbon emissions (Munshi and Parikh 1994; Rokonuzzaman 2018; Bergamini et al. 2019; Cabrera et al. 2021). Automated technology is revolutionizing milk production and handling. In most circumstances, automated systems are quicker and more accurate. Milking robots, also known as automatic milking systems (AMS), have proven to be a very effective and crucial implementation of automation in the dairy industry (Vik et al. 2019). Dairy process simulation is helpful for a variety of reasons, including designing a new dairy production plant, addressing bottleneck problems in an existing structure or combination with plant improvements, and assisting with planning and control in the face of a highly complicated product and raw-material flow (Camejo et al. 2018). Robotic milking methods use AI to determine whether the cattle need to be milked and to inform farmers of any issues with the cattle's food habits, milk quality, and other parameters (Rodenburg 2017). AI also has the potential to integrate the massive amounts of data produced on dairy farms, the unavailability of which is a significant contributing factor to the continued prevalence of problems, including short life spans, unsatisfactory performance, and deteriorating health. India is implementing AI-based technologies, such as machine learning and the Internet of Things, to enhance milk production. Due to advances in animal identification and tracking technology, small dairy producers in India will have access to cutting-edge strategies for raising product quality while reducing wasteful spending. Technology-driven AI will help the dairy industry overcome challenges and become efficient (Pawar and Panchal 2019). The literature findings from Table 1 highlighted the gaps existing in the current dairy scenario, including stakeholder coordination, resistance to adopting technological solutions, effective data management systems, lack of transparency, ineffective food safety and quality practices, awareness, regulation, policies related to emerging technologies adoption, etc. Issues related to waste management, sustainability practices, farmers' welfare, and industrial optimizations need to be addressed through practical approaches to enhance dairy sustainability. The findings show minimal literature on the integrated dairy optimization concept, which necessitates the need for such a concept to establish a linkage between identified gaps.

3. The Concept of the White Revolution 2.0

On January 13, 1970, the White Revolution started in the Indian dairy industry as a game changer and most extensive dairy development plan. It was instrumental in India's rise from a milk-deficit nation to the world's top milk producer in 1998, surpassing the United States. The "White Revolution" operation was successful because it relied on mass production and participatory democratic processes. As a result, India became the largest milk producer, yet milk adulteration and fraud issues increased parallelly (Basu and Scholten 2012). Unhygienic practices, such as handling methods, lack of policies, and low levels of food safety and quality awareness, are some factors responsible for adulteration and fraudulent activities (Bouzembrak et al. 2019). Digital technologies have the potential to overcome issues related to quality and safety. Proper implementation of such technologies can sustainably transform the dairy industry. After the White Revolution, the dairy industry is on the verge of digital transformation. The researchers have devised the phrase "White Revolution 2.0" to describe the impending digital transformation of the dairy industry, and thus, it could be another revolution, i.e., "White Revolution 2.0". The researchers developed a conceptual framework presented in Fig. 2. Additionally, in Table 1, The researchers identified factors to establish the conceptual framework of "White Revolution 2.0" based on literature analysis.

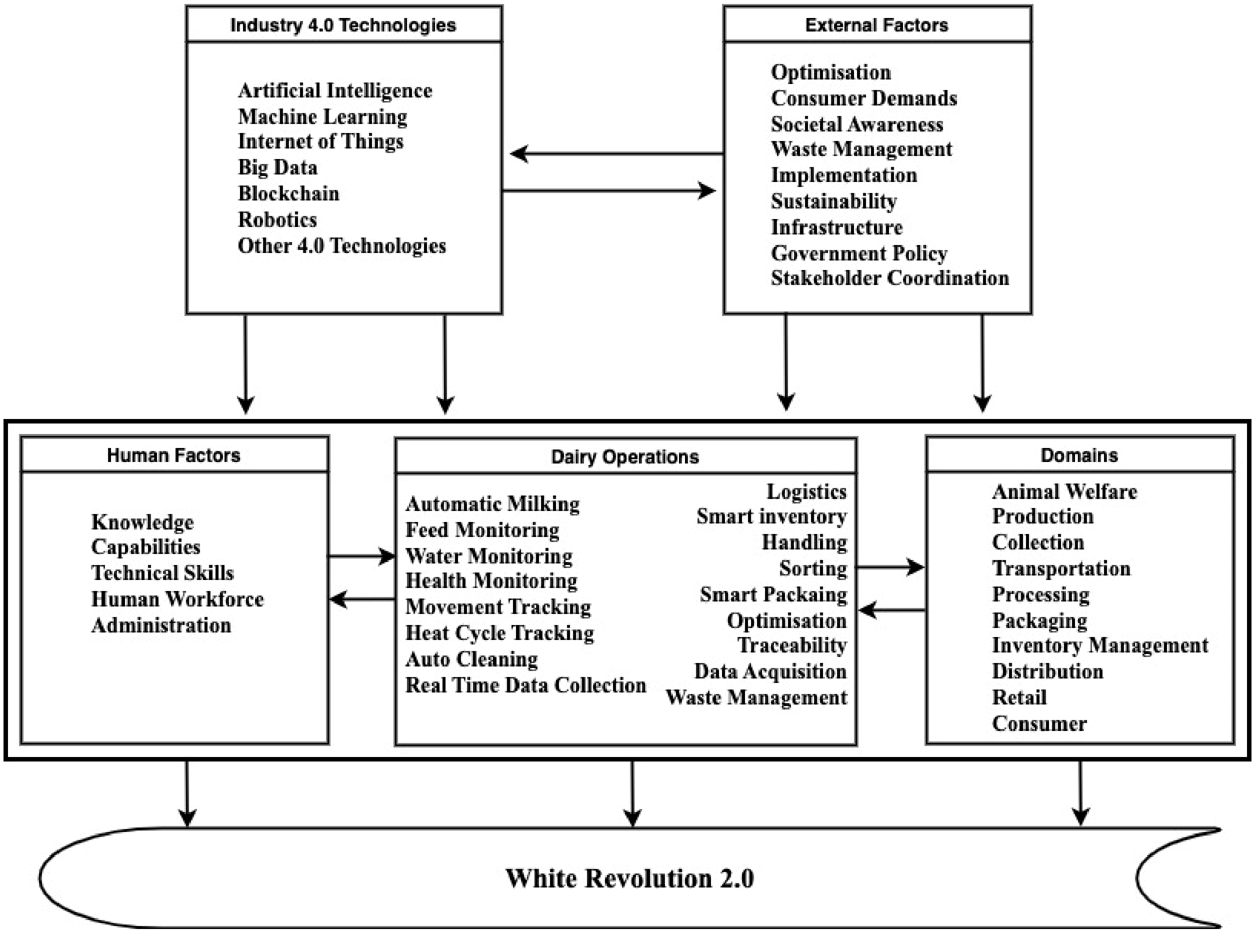

Fig. 2 Conceptual framework of "White Revolution 2.0"

The conceptual framework of "White Revolution 2.0", as illustrated in Fig. 2, is inspired by the framework developed by (Winkelhaus and Grosse 2020). Winkelhaus and Grosse developed the framework to link the literature on I4.0 technologies with the current status in that particular research area, but we adopted and modified the framework to integrate the dairy operations with stakeholders to optimize the dairy functionality. The primary modification is the practical implementation of the proposed concept. Combining the technological enablers, external factors, and human intervention in an integrated manner will present a better visualization of dairy sustainability. A more comprehensive vision of dairy sustainability can be derived by integrating technological enablers, external factors, and human intervention. This framework has three dimensions:

(1) The first dimension consists of external factors, including industrial optimization, the effect of change in consumer demands and behavior on the industry, awareness about safety and security, waste management, the emergence of I4.0 in the dairy industry, and sustainability. Moreover, issues related to existing infrastructure, stakeholders' coordination, and Government policies related to technology adoption are part of this dimension. All these components of the first dimension can be considered a proactive step towards integrated digitalization of the dairy industry. The increasing demands of consumers, the rising focus on environmental impacts and waste management, and the involvement of industrial stakeholders in implementing digital technologies are all contributing factors that underline the necessity for a practical approach to address industrial optimization. Considering all these components, industrial optimization through the proposed concept will be practically possible to achieve. Achieving industrial optimization via the proposed concept will be economically feasible in considering these various components.

(2) The second dimension is the technological aspect. It included the blocks of technology, which enable the development of an integrated environment for I4.0 technology dealing with challenges listed as external factors in the first dimension. This dimension embraces all critical technologies under the banner of I4.0 and others. AI, ML, the IoT, and blockchain are commonly used examples. This dimension can serve as the foundation for "White Revolution 2.0". This dimension involves implementing a 360-degree approach to connecting the factors the first dimension suggests. The technological dimension relates different dairy operations and I4.0 technologies for every external component in the dairy industry.

(3) Finally, the third dimension focuses on the dairy industry and is further categorized into three parts: domains of the dairy industry, human factors, and dairy tasks. The dairy operational activities and application areas of the I4.0 technologies are categorized into animal welfare, production, procurement, collection, transportation, processing, packaging, distribution, and consumer end. Human factors influence dairy tasks and technological implementation, such as skills to deploy I4.0 innovations and limitations posed by the human workforce, which can affect output quality and efficiency. Human factors such as their skills and knowledge, physical capabilities, decisions, and, most importantly, their perspective towards transformations in technological adoptions all impact dairy efficiency and productivity. Humanly decisions related to adopting innovative technological solutions for dairy optimization also significantly impact the advantages from the technological dimension.

The main challenge is integrating technology into dairy operations such as milking, monitoring animal activities and health, feeding the animals automatically, sorting and processing the products, and keeping track of inventories and transportation (Jideani et al. 2020). Industry 4.0 technologies and dairy operations are interlinked because these technologies are being used all over the dairy industry. Accordingly, using these technologies in the dairy supply chain can be termed dairy digitalization. Within the I4.0 context, dairy is being digitalized after incorporating technologies (Malik et al. 2023). The researchers termed it "White Revolution 2.0", denoting the digital revolution in the dairy industry. As shown in Fig. 1, "White Revolution 2.0" presents the linkage of all three dimensions and points towards practical implementation of the concept. For example, if any component emerges for external factors that will require related technology from a technological dimension with the impact of human factors and associated dimensions, (Khanna et al. 2022) provide an example to link I4.0 technologies with dairy operations such as traceability, safety and quality, and sustainability which gives a brief overview of the functionality of technological integration in real-world scenarios.

4. Dairy Industry 4.0 Technologies and Enablers

By the end of the White Revolution, also known as Operation Flood, around 73,930 cooperatives had been established, uniting over 3.5 crore dairy farmers (Prabakaran 2015). Thanks to the White Revolution, hundreds of cooperatives across India are thriving and accomplishing their goals efficiently. In summary, the revolution brought prosperity to many rural areas of India. However, with the increase in population and consumer demands, the dairy industry faces challenges in maintaining food safety and security. In this, technology can play an important role. The following section outlines the key technologies and their applications in the dairy industry.

4.1 Industry 4.0 Technologies

4.1.1 Robotics and Automation

Robotics is the study of robots and integrating computers for their management, sensing, and data processing with benefits such as increased productivity, less space requirement, more straightforward mechanical solutions, and better cleanliness (Heema et al. 2022). The dairy industry has lagged behind other sectors in using robots because of the difficulty in designing manipulators to handle products, which are incredibly diverse in size, shape, and composition. However, robotics has various potential uses in the dairy and food industries, including grading food products, picking and placing activities, packaging and palletizing, and dairy production and processing (Prasad Kamdhenu and Prasad 2017).

4.1.2 Big Data (BD)

BD analytics is undoubtedly an effective tool at the producer's disposal when gathering information on dairy products to make informed business decisions. BD is linked to the constant, rapid, and massive generation of many forms of unstructured data (Zhang et al. 2021). In addition, BD is identified by its status as data of high reliability and significance. Data science is increasingly used in the dairy industry to create data through sensors (Hopkins and Hawking 2018). These sensors produce information about the livestock's physiological or behavioral aspects (Rutten et al. 2013). It can also assist in identifying consumer and market patterns and the development of new services and products (Fuentes et al. 2020).

4.1.3 Internet of Things (IoT)

The Internet of Things refers to the movement of information among networked computer machines and devices (Bouzembrak et al. 2019). It consists of physical equipment that gathers data, a network that sends the information, and an interface layer that contains IoT software and services. IoT has supported the development of integrated devices, resulting in a growth in intelligent applications (Kim and Park 2016). It is frequently used in the production process to improve traceability and transparency. Wearable IoT devices enable real-time monitoring and tracking, as well as employee safety, productivity, and food safety (Accorsi et al. 2017). IoT and information strategies are expanding the possibilities for modern dairy production. IoT can benefit farmers by providing smart embedded sensors that keep them informed on the state of each animal.

4.1.4 Augmented Reality (AR)

Augmented reality enhances visualization of the actual world. Augmented reality in production operations has increased performance efficiency compared to conventional practices, yet it requires employee training to gain effectiveness and capabilities (Berkemeier et al. 2019). The AR application offers better, more reliable, and more precise dairy assessment while leveraging the industry's dairy evaluators' knowledge and expertise. During the last few years, the dairy industry has used novel techniques to boost animal production, revenue, and welfare. Alongside increased data acquisition and processing, AR aims to emphasize physical world aspects, increase knowledge of such elements, and extract meaningful and accessible understanding that can be utilized in practical systems (Piekutowska et al. 2018).

4.1.5 Cyber Security

Cybersecurity is protecting data and digital technology infrastructures like computers and networks and the availability of personnel with the necessary expertise. Cybercrime and cyber-enabled crime are rising worldwide, seriously affecting numerous markets and production sectors (including enterprises, universities, healthcare, government sites, etc.). When an industry adopts or implements cutting-edge technology, security flaws in that system become a top priority (Culot et al. 2019). In a recent cybercrime case, the American dairy company H.P. Hood Dairy temporarily shut down 13 factories nationwide. Hood was forced to dispose of some dairy goods due to the shutdowns, and the company has warned that some consumers may experience delays and cancellations while the operations get “back up and running” (Gardizy 2022).

4.1.6 Blockchain

Through blockchain, the dairy industry can demonstrate its proficiency in dairy production. The technique consists of a digital identifier applied to the packaging of each dairy product that can trace product origin. These identifiers can provide information about animal welfare to dairy operational activities such as quality, security, and managerial aspects. These identifiers can provide a complete audit trail from the farm-to-fork journey of milk and milk products (Khanna et al. 2022). The producers of counterfeit milk products, who intend to disrupt the industry, are the intended target of this technology. Regarding sustainability, the dairy supply chain has never been very effective (Wang et al. 2022). Producers had adopted many illegal methods to increase their profit. The decentralized and distributed nature of blockchain can deal with such problems to guarantee the traceability of animals and dairy. As a result, blockchain technology can boost trust in food quality and safety among market regulators and customers (Kumar and Kumar 2020).

4.1.7 Imaging Technology

Imaging technology is widely used in the supply network to visually observe products in the production process with minimum human involvement. Industry 4.0 techniques facilitate integrating systems that can observe and act to various scenarios depending on already defined parameters by directly making quick production decisions (Kang et al. 2021). Several imaging technologies are available, including spectroscopic techniques, X-ray imaging, digital and analog processing, near-infrared imaging, and smell imaging (Siedliska et al. 2018). Such approaches involve taking photos in real-time, displaying them on systems, and immediately analyzing the data to produce control instructions (Chu et al. 2020).

4.1.8 Simulation

Developing an industrial process simulation model can help predict the process's response, essential for making decisions and optimizing its performance. When done with reasonable accuracy, the simulation model greatly aids in studying the operation, efficiency, and trends of product or process variables. In addition, the simulations have been tested for years with many essential users, ensuring their accuracy (Munir et al. 2016). Although the simulation model is well-known in many fields, the chemical and petrochemical characteristics of dairy products have kept the technology from gaining traction in the dairy industry. The milk's structure and the time-dependent changes that occur in it are also significant factors (Campbell and Thomson 1998).

4.1.9 Integration

Integration plays an essential role in the growth of any industry. However, management, analysis, and control parts have traditionally been considered separate components of the industry management system. This categorization is becoming a hurdle in the communication of machines and sensors (Roh et al. 2021). Data created by the industry's machinery, suppliers, and software programs are combined with advancements in automation and integration (Demirbas et al. 2004). The interconnection and thorough integration of equipment and systems is made possible by integrating data horizontally and vertically. All data created at any level of an organization can be stored, accessed, and analyzed for further insights in one place and then mined for insights. This integration will be helpful in improving quality, cost, and productivity (Cabrera and Fadul-Pacheco 2021).

4.1.10 Artificial Intelligence

Artificial intelligence (AI) is among the technologies of I4.0, transforming traditional management practices. AI is described as the capacity of machines to employ algorithms, interpret information, and apply what they have learned to make decisions in a human-like manner (Kutyauripo et al. 2023). AI has several applications, including efficient optimization of the dairy business, online payment and data administration, real-time monitoring of calves, and precocious illness diagnosis (Pournader et al. 2021). The adoption of AI in the dairy industry is rapidly increasing. Keeping dairy cattle in optimal biological and physical health can significantly improve the current situation for dairy farmers (Krpalkova et al. 2020). With a more commercially viable approach to dairy production comes renewed optimism and exciting possibilities for the dairy industry (Chidinma-Mary-Agbai 2020).

4.1.11 Cloud Computing

Applications, data storage, and data processing techniques can be accessed and used in a cloud environment. The term "cloud computing" refers to a service delivery model in which users have near-constant, anywhere-access to a mutual pool of programmable computing resources (such as network systems, storage, servers, and interface) which can be quickly accessed with no effort on the part or connection from the provider (Mustapha et al. 2021). In both directions, information can move between back-end servers and front-end users in the cloud (Gill et al. 2019). Within the dairy industry, many cloud-based solutions integrate several operations and facilitate real-time management on a cloud-based system. Data availability, monitoring, demand-supply management, and many other vital activities are handled using cloud computing (Jukan et al. 2019).

4.1.12 Additive Manufacturing

Additive manufacturing is a technology that enables the 3D reproduction of an already digitally created design (Fahmy et al. 2020). This technique allows for the commercial production of complicated and durable products by combining material layers, including metal, plastic, or ceramic, until the 3D object is produced (Haug et al. 2023). Accuracy in product development, reduced human errors, personalization, decreased transportation and production costs, and significant agility, flexibility, and adaptation for production lines are key advantages of this I4.0 innovation (Sepasgozar et al. 2020). 3D printing enables the production of uniquely shaped panner, cheese, ice creams, and chocolates, which appeal to consumers and boost the industry's revenue (Lipton et al. 2015). Researchers recently discovered a new method for 3D printing milk-based sweets that prevents spoilage at ambient temperature (Lee et al. 2020).

4.1.13 Machine Learning

Machine learning (ML) entails novel data analysis methods, which are especially appealing for analyzing massive datasets (Abidi et al. 2022). In agriculture, dairy producers employ many sensors that generate enormous amounts of information. ML approaches are used to forecast data in the dairy industry, like milk production and energy consumption. Producers track herd statistics using livestock management software, behavioral monitoring, feed schedules, breeding cycles, and health information (Cockburn 2020). Consequently, the massive volume of data related to the dairy industry is becoming accessible. The absence of system integration makes it challenging to assess the dairy farm's records. In summary, ML can build and enhance farmers' decision-making within the dairy industry (Shine and Murphy 2022).

4.2 Adoption Challenges and Benefits Digital Technologies

Dairy firms are slowly implementing I4.0 technology to boost technological advancement and improve operational procedures; however, the widespread adoption of technology is still a concern (Yadav et al. 2020). A significant barrier is the associated cost of implementing advanced technologies such as IoT sensors, automation, and data analytics. Setting aside the resources required for such changes can be time-consuming for several small to medium-sized dairy businesses. The complicated nature of integrating data from multiple sources is another challenge. Dairy farms and processing plants produce large amounts of data, so it is critical to establish robust and reliable data collection, storage, and analysis systems (Gargiulo et al. 2018).

Furthermore, data security and privacy concerns slow down the broad implementation of such technologies. Table 2 presents a brief segment about existing adoption challenges and potential applications of I4.0 technologies. Despite these challenges, adopting I4.0 can offer several advantages to the dairy industry.

Table 2 Technological Challenges and Potential Benefits in the Dairy Industry

Higher organizational effectiveness can lead to optimized efficiency and reduced cost through technological innovation and real-time data analytics. IoT sensors and data predictive analytics can enhance product quality and uniformity, maintaining customers obtain superior quality products (Newton et al. 2020).

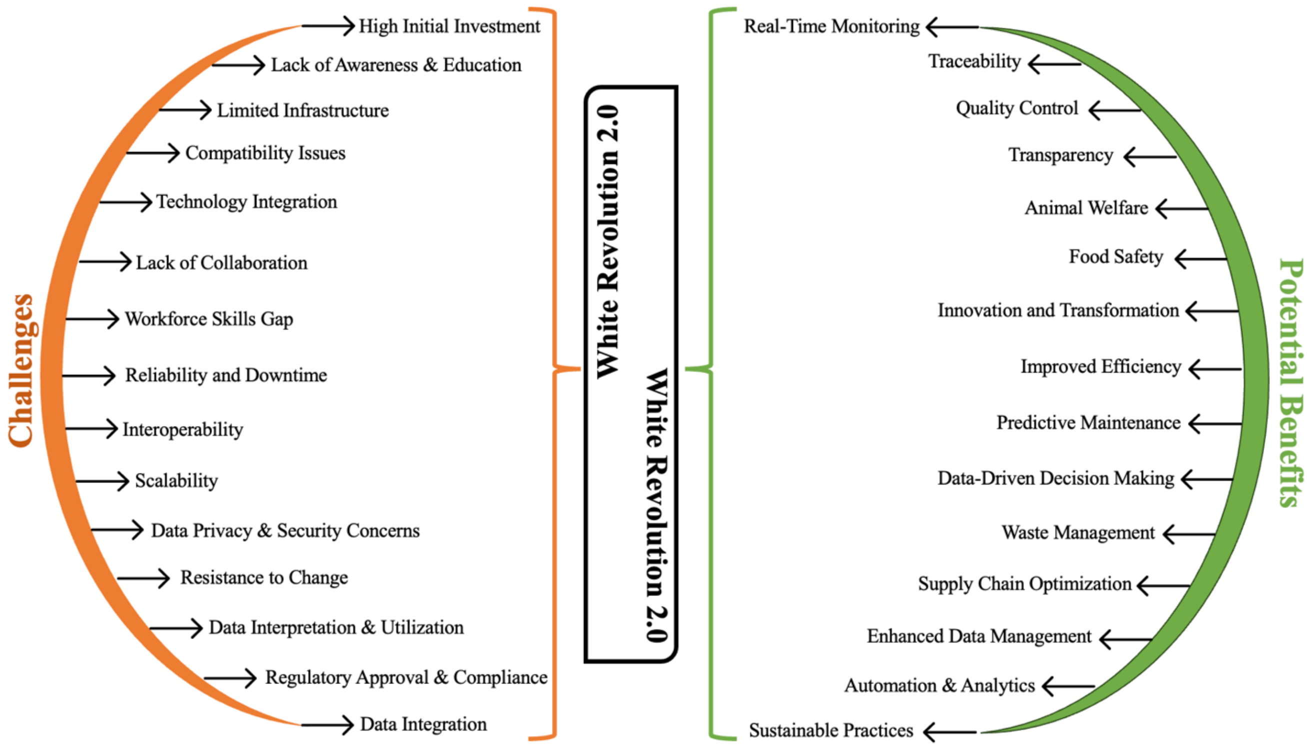

Fig. 3 Bridging the challenges and potential benefits through White Revolution 2.0

The proposed concept of White Revolution 2.0 bridges the gap between challenges and potential benefits for the dairy industry, as illustrated in Fig. 3. Also, I4.0 technologies enable traceability and transparency within the dairy industry, facilitating stakeholders to follow the origin of products and improve transportation and storage. Devising appropriate maintenance strategies, including predictive maintenance, lowers interruptions and maintenance costs, whereas resource optimization promotes sustainability and lowers environmental impact (Khanna et al. 2022). The dairy industry's advancement in implementing I4.0 innovations could offer possibilities for sustainable practices, improved competitiveness, and better consumer satisfaction. Finally, the dairy industry's digital evolution will be accelerated by ongoing initiatives to address adoption challenges and capitalize on possible advantages (Casino et al. 2020).

5. Need for White Revolution 2.0 in the Indian Context

The factors identified in Table 1 show that technological intervention in the dairy industry is already in action but is divided into different segments. An integrated flow and the linkage in the dairy industry from farm-to-fork activities seem missing. The proposed concept of "White Revolution 2.0" enables each component of the dairy industry to explore the possible opportunities in the technological context as per existing challenges. Other concerning issues discussed by (Malik et al. 2023) indicate the necessity of the proposed concept in the dairy industry. According to previous studies, milk has been observed to be among the most popular food products to be tampered with. The increasing number of fraudulent milk activities in the dairy industry further proves that digital technologies are essential. These innovations allow early detection and avoidance of milk fraud(Malik et al. 2022). For example, using blockchain technology, milk can be traced from farm-to-fork activities to detect and prevent fraud. IoT sensors can further monitor the milk temperature and other storage conditions to detect tampering with the product (Khanna et al. 2022). Existing issues such as adulteration, counterfeiting, transparency, supply chain optimization, etc., indicate the need for the proposed concept.

5.1 Milk Adulteration and Fraud Cases

The increased dairy production has resulted in rising issues about the quality and purity of milk and its derivative products. Milk fraud has happened throughout time and is still an essential worldwide problem. Previous academic research has shown that adulterated milk products can be encountered in many regions worldwide, especially emerging nations such as India, where milk production is massive but unregulated techniques are prevalent (Montgomery et al. 2020; Virto et al. 2022). Table 3 offers a summary of issues related to milk adulteration and fraud in India and throughout the globe. The researchers checked the literature related to milk adulteration and fraud cases. Information was also collected from official FSSAI reports 2018, which helped to analyze the status of adulteration cases.

Table 3 Adulteration and Milk Fraud Cases

The adulteration cases reported in Table 3 show that the proposed “White Revolution 2.0” concept can address such issues by integrating technological solutions for various dairy operations. A successful implementation using blockchain-enabled traceability for dairy was done by (Khanna et al. 2022) to enhance dairy transparency. Many researchers propose similar frameworks for the dairy industry to improve food safety and quality through digital technological solutions (Azevedo et al. 2023). Successful implementation of I4.0 technologies such as circular economy initiatives (Hettiarachchi et al. 2022), sustainable solutions (Despoudi et al. 2021), smart manufacturing (Zheng et al. 2018), additive manufacturing (Butt 2020), quality management (Baran and Polat 2022), and logistics (Hopkins and Hawking 2018) indicates the game changer potential of I4.0 integration with supply chain operations.

Section 3 discusses the concept of “White Revolution 2.0” and I4.0 technologies transforming the dairy industry more effectively and efficiently. After analyzing the literature related to the interventions of I4.0 within the dairy industry and identifying pertinent factors as presented in Table 1, The researchers modified the conceptual framework shown in Fig. 2. Accordingly, a framework is presented in a more organized and detailed manner, highlighting the importance of digitalization within the dairy industry.

5.2 Proposed Key Features of White Revolution 2.0

The framework is refined as per the findings of Section 3, represented in Fig. 4.

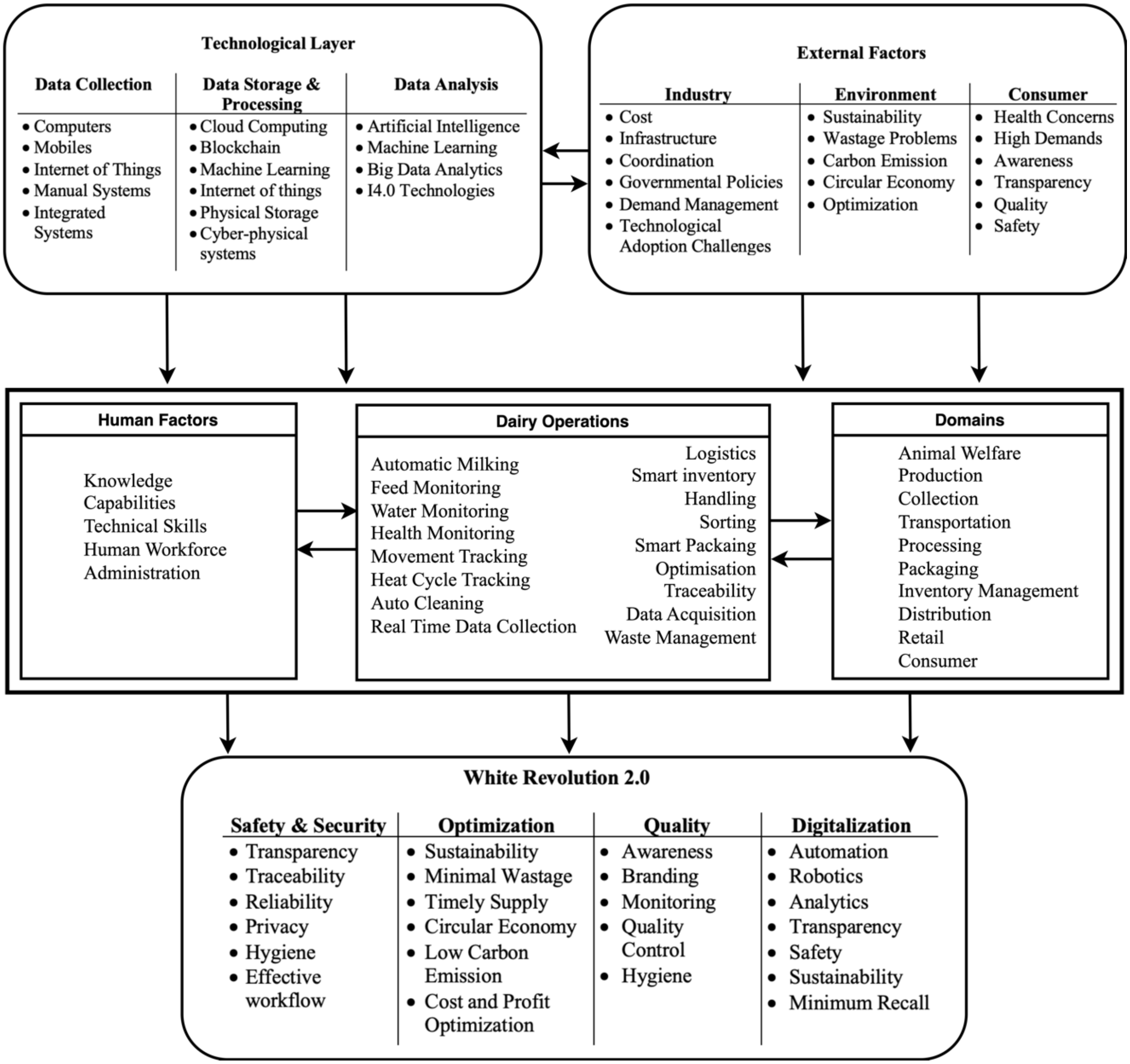

Fig. 4 Modified Conceptual framework of “White Revolution 2.0”.

5.2.1 Technological Layer

Data is the foundation of any industry, and technologies rely on it. Based on the findings, The researchers classified the technologies into three categories: (a) data collection and generation technologies, (b) data storage and processing technologies, and (c) data analysis technologies. These technologies are critical in information generation to plan and control complex operational activities temporally and spatially. IoT devices play an essential role in this regard. Handling the enormous amount of data created by IoT is difficult but essential to achieve strategic decision support. BD is essential in handling and managing these complex data sets (Lokhorst et al. 2019). This dimension indicates the linkage between existing I4.0 technologies and dairy operations related to external factors and dairy domains. The literature suggests that the increment in the adoption of technological solutions, such as technologies for data collection, processing, and analysis, has increased in the past few years; however, the industry still lacks in implementing an integrated system to use technologies to their maximum potential.

5.2.2 External Factors

The second dimension shows modified external factors into three categories: industry, environment, and consumer, influencing White Revolution 2.0. The industrial dimension is related to the need for proper infrastructure, cost, lack of coordination between dairy stakeholders, and other challenges associated with adopting I4.0 technologies. Government policies related to I4.0 technologies are also impactful factors. The environmental dimension includes the effects of I4.0 adoption in the dairy industry. Accordingly, the main factors are wastage, carbon footprints, and related sustainability issues. The consumer dimension relates to consumers' awareness of food safety and security, the importance of a transparent supply chain, and health concerns. Consumers demand a transparent system with safe and hygienic food. The evolution in external factors directly creates the need to adapt and evolve with time by employing cutting-edge solutions to address the challenges. The third dimension is divided into human factors, dairy tasks, and domains. The first part, human factors, indicates the acceptability of technological interventions by the workforce in different dimensions. Then comes the dairy tasks from farm-to-fork activities. Automation in production, real-time monitoring in processing, handling, and packaging in inventory, transportation in distribution, and traceability during the complete process are some essential tasks in the dairy industry (Bag et al. 2021; Khanna et al. 2022). Many benefits of robotics are undeniable, including increased security, reliability, and productivity. The dairy industry is labor-intensive, leading to high labor costs (Clay et al., 2019). Optimizing productivity and lowering labor expenses will have a substantial impact on revenue. Much human labor in the dairy and food industries requires quick, repeated, and monotonous action, resulting in poor work satisfaction (Ahmad Nayik 2015). As a result, there is insufficient product quality management and a high rate of workplace accidents. Robotics can perform tasks with improved precision, accuracy, and shorter timeframes than humans (Rodenburg 2017; Sain and Singh 2020). Factors in the domains section are just different segments of the dairy industry where I4.0 technologies play a crucial role.

5.2.3 Applications of I4.0

The application of I4.0 in the dairy industry mainly focuses on optimization in operational activities. The objectives of White Revolution 2.0 can be structured according to the dimensions of the modified framework, which are (a) safety and security, which deals with adulteration issues, making the supply chain traceable and transparent (Khanna et al. 2022); (b) optimization, which includes sustainability, waste management, cost, profit and reduction in carbon emission (Malik et al. 2022); (c) Quality, which deals with monitoring the processing and making more hygienic and safe products (Sain and Singh 2020); (d) the dimension digitalization introduces the central concept of White Revolution 2.0 into the dairy industry. Automation using I4.0 technologies is part of this dimension. Some examples, such as commercial food production, now frequently employ extrusion-based methods; however, these processes typically generate excessive heat to integrate delicate ingredients like milk safely. To get around this problem, the researchers identified ways to modify the rheological composition of milk powder, resulting in a new variety of edible inks rather than rethinking the printing process. The Singaporean team used their innovative dairy-based 3D printing components to create a wide range of delectable, suggesting that future culinary breakthroughs are possible (Hati and Khamrui 2018). Data analytics-based decision-making in animal welfare, milk production, and demand forecasting are potential benefits observed from implementing I4.0 technologies (Zhang et al. 2021). Findings indicate that White Revolution 2.0 will enhance the existing solutions, such as automated milking and IoT-based systems for data collection. This concept will improve the quality of the products and services to meet consumers' demands. The researchers also highlighted the need for more infrastructural and regulatory norms. Some challenges, such as lack of knowledge, training, and physical capabilities, were discussed from a human perspective. Thus, The researchers propose potential future research pathways to resolve these issues and promote the White Revolution 2.0 vision.

6. Discussion

Even though the conceptual framework presented in this paper gives insights into White Revolution 2.0, the literature lacks certain features defined in the conceptual framework of White Revolution 2.0. Consequently, prospects are highlighted based on the framework: Regarding external trends, only a few studies explore these driving factors in a structured manner. Therefore, a more extensive investigation of the impacts of motivating factors could help comprehend the requirements, e.g., demographic shifts and an aging workforce (McDonald et al. 2016). The influence of demographic shifts reflects on the technological adoption and implementation decisions. Shifts in demographics significantly influence technology implementation in the dairy, influencing consumer demands and organizational operating practices. Comprehending these changes is vital for synchronizing technology progress with changing customer demands and worker behavior (Malik et al. 2023). Many other factors, such as an aging workforce, consumer demands, market dynamics, social factors, and regulatory aspects, may impact the proposed concept. On a technological level, the dominance of the IoT in research is established. The literature indicates that the Internet of Things is demonstrating advancements in technological context from research aspects. In addition, further investigation is necessary to expand our understanding of technologies such as blockchain, augmented reality, virtual reality, etc., and incorporate disruptive technologies (Akbar et al. 2020).

Regarding technical acceptability, additional research could shed light on the successful aspects of implementation. Even though several technologies are discussed in the literature, economic evaluations are limited. Thus, it is difficult for businesses to evaluate the economic impact of new technologies, although future studies could provide valuable suggestions in this regard. In addition to dairy-related activities, automation of the production and welfare of animal aspects appears most frequently in the literature. Some studies also highlighted the role of technologies such as BD in decision-making related to many aspects such as nutrition, illness, mortality, life expectancy, milk production, demands, etc. (Michie et al. 2020; Roh et al. 2021).

At the same time, information management handling, decentralized traceability, management of waste, and decreased carbon footprints are less studied. In the evolution of White Revolution 2.0, which is not yet covered in the research, the impact of shifting activities could affect the organizational design, as some positions may become less important, and others would gain relevance. Therefore, the evolving organizational structures within the White Revolution 2.0 systems must be studied. Current production system interconnections and responses could be an exciting research area. From the perspective of experts, this may also necessitate significant planning and organization techniques. Providing a set of methodological tools to ensure systematic execution appears to be beneficial. The dairy industry's security and safety in the context of traceability are neglected in the research. These should be explored more deeply, particularly in decentralized systems and economic and business perspectives. Human Factors were the subject of only a few research studies, such as technological acceptability models. Although stated in numerous situations throughout the articles, the human-centred perspective was not extensively developed. Therefore, even though some technological possibilities are beneficial for easing human workload, human capabilities are pushed to fit the system rather than systems being altered to accommodate humans (Augustin et al. 2013).

A system design approach to these difficulties could show how White Revolution 2.0 incorporates human-centered perspective. This is consistent with labor scarcity, demographic shifts, and their effects on logistical systems. However, the literature could not explore these interrelationships in detail. From a methodological standpoint, it became clear that most contributions are conceptual or theoretical, supporting the conclusion that White Revolution 2.0 is a relatively new field of study. Consequently, empirical validation of the theoretical contributions is required. Mixed method approaches would be advantageous for gaining insights into a theoretically grounded and empirically confirmed image of reality (Cabrera and Fadul-Pacheco 2021).

6.1 Theoretical Implications of the White Revolution 2.0

Many researchers discussed the applications part of digital technologies, but the majority of the research was focused on segmented dairy areas. Research on various aspects such as quality, traceability, and environmental impacts can be addressed using the technological integration concept, leading to supply chain optimization and transparency. The authors provided an overview of digital technologies, their applications in several dairy operations, and the challenges associated with implementing these technologies, which will open the gates for future research in every aspect of dairy from top to bottom. The proposed concept, "White Revolution 2.0", provides theoretical and practical implications that considerably improve understanding and managerial decisions in the dairy industry. The conceptual implications of the current research contribute to the collection of information on Industry 4.0 by outlining the adoption of technological innovations in the dairy industry. To promote an expanded awareness of the potentially transformative impact of Industry 4.0 technologies, it shows a theoretical framework highlighting the potential advantages and challenges of implementing them in the dairy industry context. Research on integrated technological advancements in the dairy industry is still lacking, but this study presents an integrated overview. Overall, the study adds to theoretical knowledge and provides helpful information to the dairy industry for the effective and beneficial adoption of Industry 4.0 technologies beneath the optimistic structure of White Revolution 2.0.

6.2 Practical Implications of the White Revolution 2.0

The dairy industry faces several challenges in adopting innovative technologies to enhance operational efficiency. Integrating innovative technologies, developing alternate methods, and formulating strategies from an administrative and business perspective are appropriate options for addressing these obstacles. The proposed framework can serve as a roadmap to implement the various digital technologies and integrate the dairy operations with dairy stakeholders. On a practical level, the study encompasses significant implications for decision-makers and stakeholders in the dairy industry. The analysis assists in smart decision-making that could correlate with organizational goals by providing information on the practical application of Industry 4.0 technologies. The identified challenges are a foundation for risk minimization and backup strategies in the digital evolution. The key advantages, such as operational optimization, enhanced product quality, and supply chain transparency, offer tangible possibilities for stakeholders to boost productivity, product competitiveness, and customer trust. Additionally, this study promotes innovation and competitive advantage, encouraging dairy organizations to consider creative supply chain approaches. Collaboration is encouraged among dairy industry players and technologists, resulting in customized solutions and productive associations. Policymakers can use findings from the research to design guidelines that promote technological adoption while complying with standards set by the industry. Based on the literature findings and proposed concept, the following could help researchers, industrial management, and policymakers to create an efficient and effective dairy industry:

- The need of the hour is the research focused on developing practical frameworks and models for industries to implement effectively.
- A strategic collaboration between academia and industry could help to validate the research and develop effective and timely solutions.
- The industry's participation in innovation outreach programs to address the challenges would be much appreciated.
- Government authorities and policymakers' support for adequate funding, infrastructural and skill development programs, and modified regulations, especially in the technological context, is the need of the hour for the dairy industry.

7. Conclusion

The dairy industry faced many difficulties during the pandemic, such as a lack of labor, problems in production and processing, logistics, and many other disruptions. Industry 4.0 technologies are essential in managing the dairy supply chain operations. This study examined the potential uses of digital technologies and how such technologies can contribute to a digital revolution in the dairy industry. The researchers categorized the literature findings and proposed a conceptual framework. Based on the literature analysis, the term White Revolution 2.0 is proposed. The primary research pathways and strategies of White Revolution 2.0 systems are discussed. The review provides an overview of the current level of research in the direction of the proposed concept of White Revolution 2.0. The study is based on the theory that the proposed framework is a vital component of the future perspective in the dairy industry. This review provides insight into opportunities to improve the dairy system by incorporating I4.0 technology and providing innovative solutions.

Furthermore, this work highlights the significance of human factors, external variables, and technology adoption in dairy supply chain operations in the evolution of White Revolution 2.0. Based on the discussion, new prospects are outlined, indicating the need for a digital revolution in the current dairy system. The White Revolution 2.0 could help address many challenges in the dairy industry through an integrative approach. The proposed concept integrates emerging technologies in the dairy industry to establish a technological linkage between all segments and stakeholders associated with the dairy industry. This review paves the way for future technological innovations that can be developed and integrated to enhance the dairy structure in the context of optimization, quality, safety and security, and digitalization. Thus, this review encourages the diffusion of knowledge. The concept of White Revolution 2.0 can be the first step towards integrated digitalization in the Indian dairy industry. Future research can use the proposed concept as a foundation to explore any component of the dairy industry.

In addition, unconsidered technology and applications can be studied as potential new market offerings. In food industry research, the term "4.0" is widely accepted. However, dairy could have used it more consistently. Although there is a growing body of scholarly research on I4.0, the dairy industry must be thoroughly studied. This evaluation may serve as a foundation for interlinking operations in the digital dairy system, and its purpose is to promote future study in this area. The term White Revolution 2.0 is proposed based on the current status of the dairy industry in a technological intervention context. The digital revolution is not limited to the proposed concept; it could offer many more improvements. If another movement emerges after the White Revolution, it should focus on quality, the factors discussed in the proposed conceptual framework, and production capacity. The researchers proposed the concept for the complete dairy segment for technological interventions, and White Revolution 2.0 addressed all the farm-to-fork activities. The proposed term "White Revolution 2.0" has been coined only to address the digital revolution in the dairy industry here. Although the 'White Revolution' was a game changer movement in India, White Revolution 2.0 is not only limited to the Indian context; it can be generalized globally. The global dairy industry needs digitalization to integrate complete dairy operations, as development has no boundaries.

References

Abidi MH, Mohammed MK, Alkhalefah H (2022) Predictive Maintenance Planning for Industry 4.0 Using Machine Learning for Sustainable Manufacturing. Sustainability 14:3387. https://doi.org/10.3390/su14063387

Accorsi R, Bortolini M, Baruffaldi G, Pilati F, Ferrari E (2017) Internet-of-things Paradigm in Food Supply Chains Control and Management. Procedia Manuf 11:889–895. https://doi.org/10.1016/J.PROMFG.2017.07.192

Agrawal S, Agrawal R, Kumar A, Luthra S, Garza-Reyes JA (2023) Can industry 5.0 technologies overcome supply chain disruptions?—a perspective study on pandemics, war, and climate change issues. Operations Management Research. https://doi.org/10.1007/s12063-023-00410-y

Ahmad Nayik G (2015) Robotics and Food Technology: A Mini Review. J Nutr Food Sci 05. https://doi.org/10.4172/2155-9600.1000384

Akbar MO, Shahbaz Khan MS, Ali MJ, Hussain A, Qaiser G, Pasha M, Pasha U, Missen MS, Akhtar N (2020) IoT for Development of Smart Dairy Farming. J Food Qual 2020. https://doi.org/10.1155/2020/4242805

Akbari M, Hopkins JL (2022) Digital technologies as enablers of supply chain sustainability in an emerging economy. Operations Management Research 15:689–710. https://doi.org/10.1007/s12063-021-00226-8

Akzar R, Umberger W, Peralta A (2022) Understanding heterogeneity in technology adoption among Indonesian smallholder dairy farmers. Agribusiness. https://doi.org/10.1002/agr.21782

Alonso RS, 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 98:102047. https://doi.org/https://doi.org/10.1016/j.adhoc.2019.102047

Augustin MA, Udabage P, Juliano P, Clarke PT (2013) Towards a more sustainable dairy industry: Integration across the farm-factory interface and the dairy factory of the future. Int Dairy J 31:2–11. https://doi.org/10.1016/j.idairyj.2012.03.009

Azevedo P, Gomes J, Romão M (2023) Supply chain traceability using blockchain. Operations Management Research 16:1359–1381. https://doi.org/10.1007/s12063-023-00359-y

Bag S, Yadav G, Dhamija P, Kataria KK (2021) Key resources for industry 4.0 adoption and its effect on sustainable production and circular economy: An empirical study. J Clean Prod 281. https://doi.org/10.1016/j.jclepro.2020.125233

Baran E, Polat TK (2022) Classification of Industry 4.0 for Total Quality Management: A Review. Sustainability (Switzerland) 14:1–20. https://doi.org/10.3390/su14063329

Basu P, Scholten BA (2012) Crop-livestock systems in rural development: Linking India's Green and White Revolutions. Int J Agric Sustain 10:175–191. https://doi.org/10.1080/14735903.2012.672805

Basunathe VK, Sawarkar SW, Sasidhar PVK (2010) Adoption of dairy production technologies and implications for dairy development in India. Outlook Agric 39:134–140. https://doi.org/10.5367/000000010791745385

Bergamini R, Nguyen T van, Elmegaard B (2019) Simplification of Data Acquisition in Process Integration Retrofit Studies Based on Uncertainty and Sensitivity Analysis. Front Energy Res 7:1–19. https://doi.org/10.3389/fenrg.2019.00108

Berkemeier L, Zobel B, Werning S, Ickerott I, Thomas O (2019) Engineering of Augmented Reality-Based Information Systems: Design and Implementation for Intralogistics Services. Business and Information Systems Engineering 61:67–89. https://doi.org/10.1007/s12599-019-00575-6

Bhatt SM, Bhatt SR (2016) Assessment of synthetic milk exposure to children of selected population in Uttar Pradesh, India. Indian Journal of Research 7:22–34

Bianchi MC, Bava L, Sandrucci A, Tangorra FM, Tamburini A, Gislon G, Zucali M (2022) Diffusion of precision livestock farming technologies in dairy cattle farms. Animal 16:100650. https://doi.org/10.1016/j.animal.2022.100650

Borchers MR, Bewley JM (2015) An assessment of producer precision dairy farming technology use, prepurchase considerations, and usefulness. J Dairy Sci 98:4198–4205. https://doi.org/10.3168/jds.2014-8963

Bouzembrak Y, Klüche M, Gavai A, Marvin HJP (2019) Internet of Things in food safety: Literature review and a bibliometric analysis. Trends Food Sci Technol 94:54–64. https://doi.org/10.1016/j.tifs.2019.11.002

Bueno A, Godinho M, Latan H, Frank AG, Jose C, Jabbour C, Miller G (2023) International Journal of Production Economics The role of Industry 4 . 0 in developing resilience for manufacturing companies during COVID-19. 256. https://doi.org/10.1016/j.ijpe.2022.108728

Butt J (2020) Exploring the interrelationship between additive manufacturing and industry 4.0. Designs (Basel) 4:1 – 33. https://doi.org/10.3390/designs4020013

Cabrera VE, Barrientos-Blanco JA, Delgado H, Fadul-Pacheco L (2020) Symposium review: Real-time continuous decision making using big data on dairy farms. J Dairy Sci 103:3856–3866. https://doi.org/10.3168/jds.2019-17145

Cabrera VE, Fadul-Pacheco L (2021) Future of dairy farming from the Dairy Brain perspective: Data integration, analytics, and applications. Int Dairy J 121

Cabrera VE, Wangen SR, Zhang F, Fourdraine RH, Mattison JM, Sciences D, Record D, Systems M, Carolina N (2021) The US Dairy Brain Project : Data integration and data applications for improved farm decision-making. Proceedings ICAR Conference 227–232

Camejo IM, Sailema GLA, Carrillo KMG, Verdecia JAM (2018) Computational Simulation Model of Milk Production Process, Case Study: Dairy Plant FCP-ESPOCH. KnE Engineering 1:179. https://doi.org/10.18502/keg.v1i2.1494

Campbell C, Thomson N (1998) Simulation in the Dairy Industry-a case stud5 using SIMUL8. OR Insights 11:22–28

Casino F, Kanakaris V, Dasaklis TK, Moschuris S, Stachtiaris S, Pagoni M, Rachaniotis NP (2020) Blockchain-based food supply chain traceability: a case study in the dairy sector. Int J Prod Res 1–13. https://doi.org/10.1080/00207543.2020.1789238

Chakraborty K, Ghosh A, Pratap S (2023) Adoption of blockchain technology in supply chain operations: a comprehensive literature study analysis. Operations Management Research. https://doi.org/10.1007/s12063-023-00420-w

Chidinma-Mary-Agbai (2020) Application of artificial intelligence (AI) in food industry. GSC Biological and Pharmaceutical Sciences 13:171–178. https://doi.org/10.30574/gscbps.2020.13.1.0320

Chu X, Wang W, Ni X, Li C, Li Y (2020) Classifying maize kernels naturally infected by fungi using near-infrared hyperspectral imaging. Infrared Phys Technol 105:103242. https://doi.org/https://doi.org/10.1016/j.infrared.2020.103242

Cockburn M (2020) Review: Application and prospective discussion of machine learning for the management of dairy farms. Animals 10:1–22

Culot G, Fattori F, Podrecca M, Sartor M (2019) Addressing Industry 4.0 Cybersecurity Challenges. IEEE Engineering Management Review 47:79–86. https://doi.org/10.1109/EMR.2019.2927559

Daftary D (2019) Market-driven dairying and the politics of value, labor and affect in Gujarat, India. Journal of Peasant Studies 46:80–95. https://doi.org/10.1080/03066150.2017.1324425

dela Rue BT, Eastwood CR, Edwards JP, Cuthbert S (2019) New Zealand dairy farmers preference investments in automation technology over decision-support technology. Anim Prod Sci 60:133–137. https://doi.org/10.1071/AN18566

Demirbas N, Kenanoglu Z, Karahan Uysal O, Karagozlo C (2004) Integration in Dairy Industry in the European Union and Evaluation of the Present Situation in Turkey

Despoudi S, Spanaki K, Rodriguez-Espindola O, Zamani ED (2021) From Industry 4.0 to Agriculture 4.0 BT - Agricultural Supply Chains and Industry 4.0: Technological Advance for Sustainability. In: Despoudi S, Spanaki K, Rodriguez-Espindola O, Zamani ED (eds). Springer International Publishing, Cham, pp 13–28

Doinea M, Boja C, Batagan L, Toma C, Popa M (2015) Internet of Things Based Systems for Food Safety Management. Informatica Economica 19:87–97. https://doi.org/10.12948/issn14531305/19.1.2015.08

Duncan SE (1998) Dairy Products: The Next Generation. Altering the Image of Dairy Products Through Technology. J Dairy Sci 81:877–883. https://doi.org/10.3168/jds.S0022-0302(98)75646-2

Duruz S, Vajana E, Burren A, Flury C, Joost S (2020) Big dairy data to unravel effects of environmental, physiological and morphological factors on milk production of mountain-pastured Braunvieh cows. R Soc Open Sci 7. https://doi.org/10.1098/rsos.200638

Dutton-Regester KJ, Barnes TS, Wright JD, Rabiee AR (2020) Lameness in dairy cows: Farmer perceptions and automated detection technology. Journal of Dairy Research 87:67–71. https://doi.org/10.1017/S0022029920000497

Eastwood CR, Jago JG, Edwards JP, Burke JK (2016) Getting the most out of advanced farm management technologies: Roles of technology suppliers and dairy industry organisations in supporting precision dairy farmers. Anim Prod Sci 56:1752–1760. https://doi.org/10.1071/AN141015

Ebrahimnejad H, Ebrahimnejad H, Salajegheh A, Barghi H (2018) Use of magnetic resonance imaging in food quality control: A review. J Biomed Phys Eng 8:119–124

Eckelkamp EA, Bewley JM (2020) On-farm use of disease alerts generated by precision dairy technology. J Dairy Sci 103:1566–1582. https://doi.org/10.3168/jds.2019-16888

Edwards JP, dela Rue BT, Jago JG (2015) Evaluating rates of technology adoption and milking practices on New Zealand dairy farms. Anim Prod Sci 55:702–709. https://doi.org/10.1071/AN14065

Fahmy AR, Becker T, Jekle M (2020) 3D printing and additive manufacturing of cereal-based materials: Quality analysis of starch-based systems using a camera-based morphological approach. Innovative Food Science & Emerging Technologies 63:102384. https://doi.org/https://doi.org/10.1016/j.ifset.2020.102384

Faraz A, Lateef M, Mustafa MI, Akhtar P, Yaqoob M, Rehman S (2013) Detection of adulteration, chemical composition and hygienic status of milk supplied to various canteens of educational institutes and public places in Faisalabad. The Journal of Animal and Plant Sciences 23:119–124

Franceschini S, Grelet C, Leblois J, Gengler N, Soyeurt H (2022) Can unsupervised learning methods applied to milk recording big data provide new insights into dairy cow health? J Dairy Sci 105:6760–6772. https://doi.org/10.3168/jds.2022-21975

Fredriksson A, Liljestrand K (2015) Capturing food logistics: a literature review and research agenda. International Journal of Logistics Research and Applications 18:16–34. https://doi.org/10.1080/13675567.2014.944887

FSSAI (2012) FSSAI Conducts National Survey on Adulteration of Milk

FSSAI (2018) National Milk Safety and Quality Survey

Fuentes S, Viejo CG, Cullen B, Tongson E, Chauhan SS, Dunshea FR (2020) Artificial intelligence applied to a robotic dairy farm to model milk productivity and quality based on cow data and daily environmental parameters. Sensors (Switzerland) 20. https://doi.org/10.3390/s20102975

Gardizy A (2022) Hackers hit Hood. Dairy shut down milk production this week after 'cyber security event.' - The Boston Globe. In: BostonGlobe.com. https://www.bostonglobe.com/2022/03/18/business/school-milk-could-be-short-supply-after-hood-plants-hit-by-cyber-event/. Accessed 19 Dec 2022

Gargiulo JI, Eastwood CR, Garcia SC, Lyons NA (2018) Dairy farmers with larger herd sizes adopt more precision dairy technologies. J Dairy Sci 101:5466–5473. https://doi.org/10.3168/jds.2017-13324

Gatlan S (2021) World's leading dairy group Lactalis hit by cyberattack. World's leading dairy group Lactalis hit by cyberattack. Accessed 19 Dec 2022

Gehlot A, Malik PK, Singh R, Akram SV, Alsuwian T (2022) Dairy 4.0: Intelligent Communication Ecosystem for the Cattle Animal Welfare with Blockchain and IoT Enabled Technologies. Applied Sciences (Switzerland) 12. https://doi.org/10.3390/app12147316

Gill SS, Tuli S, Xu M, Singh I, Singh KV, Lindsay D, Tuli S, Smirnova D, Singh M, Jain U, Pervaiz H, Sehgal B, Kaila SS, Misra S, Aslanpour MS, Mehta H, Stankovski V, Garraghan P (2019) Transformative effects of IoT, Blockchain and Artificial Intelligence on cloud computing: Evolution, vision, trends and open challenges. Internet of Things 8:100118. https://doi.org/10.1016/j.iot.2019.100118

Goodarzian F, Taleizadeh AA, Ghasemi P, Abraham A (2021) An integrated sustainable medical supply chain network during COVID-19. Eng Appl Artif Intell 100. https://doi.org/10.1016/j.engappai.2021.104188

Hansen BG, Bugge CT, Skibrek PK (2020) Automatic milking systems and farmer wellbeing–exploring the effects of automation and digitalization in dairy farming. J Rural Stud 80:469–480. https://doi.org/10.1016/j.jrurstud.2020.10.028

Hassoun A, Boukid F, Pasqualone A, Bryant CJ, García GG, Parra-López C, Jagtap S, Trollman H, Cropotova J, Barba FJ (2022a) Emerging trends in the agri-food sector: Digitalisation and shift to plant-based diets. Curr Res Food Sci 5:2261–2269. https://doi.org/10.1016/j.crfs.2022.11.010

Hassoun A, Jagtap S, Trollman H, Garcia-Garcia G, Abdullah NA, Goksen G, Bader F, Ozogul F, Barba FJ, Cropotova J, Munekata PES, Lorenzo JM (2022b) Food processing 4.0: Current and future developments spurred by the fourth industrial revolution. Food Control 145:109507. https://doi.org/10.1016/j.foodcont.2022.109507

Hati S, Khamrui K (2018) 3D Printed Dairy Foods: An Emerging Technology for Dairy Industry Indian Dairyman. 70

Haug A, Wickstrøm KA, Stentoft J, Philipsen K (2023) Adoption of additive manufacturing: A survey of the role of knowledge networks and maturity in small and medium-sized Danish production firms. Int J Prod Econ 255:108714. https://doi.org/10.1016/j.ijpe.2022.108714

Heema R, Sivaranjani S, Gnanalakshmi KS (2022) An Insight in to the Automation of the Dairy Industry: A Review. Asian Journal of Dairy and Food Research. https://doi.org/10.18805/ajdfr.dr-1856

Hettiarachchi BD, Seuring S, Brandenburg M (2022) Industry 4.0-driven operations and supply chains for the circular economy: a bibliometric analysis. Operations Management Research 15:858–878. https://doi.org/10.1007/s12063-022-00275-7

Hoang TH, Nguyen NPP, Hoang NYN, Akbari M, Quang HT, Binh ADT (2023) Application of social media in supply chain 4.0 practices: a bibliometric analysis and research trends. Operations Management Research 16:1162–1184. https://doi.org/10.1007/s12063-023-00378-9

Hogan C, Kinsella J, O'Brien B, Markey A, Beecher M (2022) Estimating the effect of different work practices and technologies on labor efficiency within pasture-based dairy systems. J Dairy Sci 105:5109–5123. https://doi.org/10.3168/jds.2021-21216

Holloway L, Bear C, Wilkinson K (2014) Robotic milking technologies and renegotiating situated ethical relationships on UK dairy farms. Agric Human Values 31:185–199. https://doi.org/10.1007/s10460-013-9473-3

Hopkins J, Hawking P (2018) Big Data Analytics and IoT in logistics: a case study. International Journal of Logistics Management 29:575–591. https://doi.org/10.1108/IJLM-05-2017-0109

Huang Y, Min S, Duan J, Wu L, Li Q (2014) Identification of additive components in powdered milk by NIR imaging methods. Food Chem 145:278–283. https://doi.org/10.1016/j.foodchem.2013.06.116

Jachimczyk B, Tkaczyk R, Piotrowski T, Johansson S, Kulesza WJ (2021) IoT-based dairy supply chain - An ontological approach. Elektronika ir Elektrotechnika 27:71–83. https://doi.org/10.5755/j02.eie.27612

Jagtap S, Saxena P, Salonitis K (2021) Food 4.0: Implementation of the Augmented Reality Systems in the Food Industry. Procedia CIRP 104:1137–1142. https://doi.org/10.1016/j.procir.2021.11.191

Janssen E, Swinnen J (2019) Technology adoption and value chains in developing countries: Evidence from dairy in India. Food Policy 83:327–336. https://doi.org/10.1016/j.foodpol.2017.08.005

Jarvis J, Haertelt M, Hugger S, Butschek L, Fuchs F, Ostendorf R, Wagner J, Beyerer J (2017) Hyperspectral data acquisition and analysis in imaging and real-Time active MIR backscattering spectroscopy. Advanced Optical Technologies 6:85–93. https://doi.org/10.1515/aot-2016-0068

Jauhar S, Pratap S, Lakshay, Paul S, Gunasekaran A (2023) Internet of things based innovative solutions and emerging research clusters in circular economy. Operations Management Research. https://doi.org/10.1007/s12063-023-00421-9

Jideani AIO, Mutshinyani AP, Maluleke NP, Mafukata ZP, Sithole M v., Lidovho MU, Ramatsetse EK, Matshisevhe MM (2020) Impact of Industrial Revolutions on Food Machinery - An Overview. J Food Res 9:42. https://doi.org/10.5539/jfr.v9n5p42

Jukan A, Carpio F, Masip X, Ferrer AJ, Kemper N, Stetina BU (2019) Fog-to-Cloud Computing for Animal Farming: Towards Low-Cost Technologies, Data Exchange and Animal Welfare

Kandpal S, Srivastava A, Negi K (2012) Estimation of quality of raw milk (open & branded) by milk adulteration testing kit. Indian J Community Health 24:188–192

Kang W, Lin H, Jiang H, Yao-Say Solomon Adade S, Xue Z, Chen Q (2021) Advanced applications of chemo-responsive dyes based odor imaging technology for fast sensing food quality and safety: A review. Compr Rev Food Sci Food Saf

Kazancoglu Y, Sagnak M, Mangla SK, Sezer MD, Pala MO (2021) A fuzzy based hybrid decision framework to circularity in dairy supply chains through big data solutions. Technol Forecast Soc Change 170:120927. https://doi.org/10.1016/j.techfore.2021.120927

Khanna A, Jain S, Burgio A, Bolshev V, Panchenko V (2022) Blockchain-Enabled Supply Chain platform for Indian Dairy Industry: Safety and Traceability. Foods 11. https://doi.org/10.3390/foods11172716

Kim JY, Park DJ (2016) Internet-of-things based approach for warehouse management system. International Journal of Multimedia and Ubiquitous Engineering 11:159–166. https://doi.org/10.14257/ijmue.2016.11.10.15

Kompas T, Che TN (2006) Technology choice and efficiency on Australian dairy farms. Australian Journal of Agricultural and Resource Economics 50:65–83. https://doi.org/10.1111/j.1467-8489.2006.00314.x

Krpalkova L, Mahony NO, Carvalho A, Campbell S, Harapanahalli S, Walsh J (2020) Influence of Environmental Temperature on Dairy Herd Performance and Behaviour. International journal of agricultural and Biosystems Engineering 14:129–133

Kumar LB, Kumar VR (2020) Blockchain-based Traceability in Dairy Supply Chain Management: A Literature Review. International Journal of Science Technology and Management 9

Kutyauripo I, Rushambwa M, Chiwazi L (2023) Artificial intelligence applications in the agrifood sectors. J Agric Food Res 11:100502. https://doi.org/https://doi.org/10.1016/j.jafr.2023.100502

Lee CP, Karyappa R, Hashimoto M (2020) 3D printing of milk-based product. RSC Adv 10:29821–29828. https://doi.org/10.1039/d0ra05035k

Lipton JI, Cutler M, Nigl F, Cohen D, Lipson H (2015) Additive manufacturing for the food industry. Trends Food Sci Technol 43:114–123. https://doi.org/https://doi.org/10.1016/j.tifs.2015.02.004

Liu JM, Ren A, Yang L, Gao J, Pei L, Ye R, Qu A, Zheng X (2010) Urinary tract abnormalities in Chinese rural children who consumed melamine-contaminated dairy products: A population-based screening and follow-up study. CMAJ Canadian Medical Association Journal 182:439–443. https://doi.org/10.1503/cmaj.091063

Lokhorst C, de Mol RM, Kamphuis C (2019) Invited review: Big Data in precision dairy farming. Animal 13:1519–1528. https://doi.org/10.1017/S1751731118003439

Madsen C (2021) Cyber News Rundown: Dairy Farm Ransomware | Webroot. In: Webroot Blog. https://www.webroot.com/blog/2021/02/03/cyber-news-rundown-dairy-farm-ransomware/. Accessed 19 Dec 2022

Maldonado-Siman E, Godinez-Gonzalez CS, Cadena-Meneses JA, Ruíz-Flores A, Aranda-Osorio G (2013) Traceability in the mexican dairy processing industry. J Food Process Preserv 37:399–404. https://doi.org/10.1111/j.1745-4549.2011.00663.x

Maleko D, Msalya G, Mwilawa A, Pasape L, Mtei K (2018) Smallholder dairy cattle feeding technologies and practices in Tanzania: failures, successes, challenges and prospects for sustainability. Int J Agric Sustain 16:201–213. https://doi.org/10.1080/14735903.2018.1440474

Malik M, Gahlawat VK, Mor RS, Dahiya V, Yadav M (2022) Application of Optimization Techniques in the Dairy Supply Chain: A Systematic Review. Logistics 6

Malik M, Malik A, Gahlawat VK, Mor RS (2023) Traceability in the Indian dairy industry: Concept and practice. Int J Dairy Technol 76:758–778. https://doi.org/https://doi.org/10.1111/1471-0307.12999

Mayo LM, Silvia WJ, Ray DL, Jones BW, Stone AE, Tsai IC, Clark JD, Bewley JM, Heersche G (2019) Automated estrous detection using multiple commercial precision dairy monitoring technologies in synchronized dairy cows. J Dairy Sci 102:2645–2656. https://doi.org/10.3168/jds.2018-14738

McDonald R, Heanue K, Pierce K, Horan B (2016) Factors Influencing New Entrant Dairy Farmer's Decision-making Process around Technology Adoption. Journal of Agricultural Education and Extension 22:163–177. https://doi.org/10.1080/1389224X.2015.1026364

Mekonnen H, Dehninet G, Kelay B (2010) Dairy technology adoption in smallholder farms in "Dejen" district, Ethiopia. Trop Anim Health Prod 42:209–216. https://doi.org/10.1007/s11250-009-9408-6

Michie C, Andonovic I, Davison C, Hamilton A, Tachtatzis C, Jonsson N, Duthie CA, Bowen J, Gilroy M (2020) The Internet of Things enhancing animal welfare and farm operational efficiency. Journal of Dairy Research 87:20–27. https://doi.org/10.1017/S0022029920000680

Monshizadeh F, Sadeghi Moghadam MR, Mansouri T, Kumar M (2023) Developing an industry 4.0 readiness model using fuzzy cognitive maps approach. Int J Prod Econ 255:108658. https://doi.org/10.1016/j.ijpe.2022.108658

Montgomery H, Haughey SA, Elliott CT (2020) Recent food safety and fraud issues within the dairy supply chain (2015–2019). Glob Food Sec 26

Munien I, Telukdarie A (2021) COVID-19 supply chain resilience modelling for the dairy industry. In: Procedia Computer Science. Elsevier B.V., pp 591–599

Munir MT, Zhang Y, Yu W, Wilson DI, Young BR (2016) Virtual milk for modelling and simulation of dairy processes. J Dairy Sci 99:3380–3395. https://doi.org/10.3168/jds.2015-10449

Munshi KD, Parikh KS (1994) Milk supply behavior in India: Data integration, estimation and implications for dairy development. J Dev Econ 45:201–223. https://doi.org/10.1016/0304-3878(94)90030-2

Murphy MD, O'Mahony MJ, Shalloo L, French P, Upton J (2014) Comparison of modelling techniques for milk-production forecasting. J Dairy Sci 97:3352–3363. https://doi.org/10.3168/jds.2013-7451

Mustapha UF, Alhassan AW, Jiang DN, Li GL (2021) Sustainable aquaculture development: a review on the roles of cloud computing, internet of things and artificial intelligence (CIA). Rev Aquac 13:2076–2091. https://doi.org/10.1111/raq.12559

Neethirajan S (2020) The role of sensors, big data and machine learning in modern animal farming. Sens Biosensing Res 29:100367. https://doi.org/10.1016/j.sbsr.2020.100367

Newton JE, Nettle R, Pryce JE (2020) Farming smarter with big data: Insights from the case of Australia's national dairy herd milk recording scheme. Agric Syst 181:102811. https://doi.org/10.1016/j.agsy.2020.102811

Nurhayati K, Tavasszy L, Rezaei J (2023) Joint B2B supply chain decision-making: Drivers, facilitators and barriers. Int J Prod Econ 256. https://doi.org/10.1016/j.ijpe.2022.108721

Ögür AY (2021) Factors affecting the adoption of technology in dairy farms in the konya region of Turkey. New Medit 20:145–157. https://doi.org/10.30682/NM2103J

Pawar K, Panchal I (2019) Artificial Intelligence in Dairy Farming: A Way Forward for Improving the Health of Dairy-Cows. 8:2349–3704

Piekutowska M, Rudowicz-Nawrocka J, Kudlińska K, Niedbała G (2018) APPLICATION OF AUGMENTED REALITY IN DAIRY CATTLE MONITORING

Pournader M, Ghaderi H, Hassanzadegan A, Fahimnia B (2021) Artificial intelligence applications in supply chain management. Int J Prod Econ 241:108250. https://doi.org/10.1016/j.ijpe.2021.108250

Prabakaran M (2015) Rural Development and Milk Cooperatives in India. International Journal of Management Research and Social Science 2:58–64

Prasad Kamdhenu S, Prasad S (2017) Application of Robotics in Dairy and Food Industries: A Review. Int J Sci Environ Technol 6:1856–1864

Rodenburg J (2017) Robotic milking: Technology, farm design, and effects on work flow. J Dairy Sci 100:7729–7738. https://doi.org/10.3168/jds.2016-11715

Rodriguez-Venegas R, Meza-Herrera CA, Robles-Trillo PA, Angel-Garcia O, Rivas-Madero JS, Rodriguez-Martínez R (2022) Heat Stress Characterization in a Dairy Cattle Intensive Production Cluster under Arid Land Conditions: An Annual, Seasonal, Daily, and Minute-To-Minute, Big Data Approach. Agriculture (Switzerland) 12. https://doi.org/10.3390/agriculture12060760

Roh Y, Heo G, Whang SE (2021) A Survey on Data Collection for Machine Learning: A Big Data-AI Integration Perspective. IEEE Trans Knowl Data Eng 33:1328–1347. https://doi.org/10.1109/TKDE.2019.2946162

Rokonuzzaman Md (2018) The Integration of Extended Supply Chain with Sales and Operation Planning: A Conceptual Framework. Logistics 2:8. https://doi.org/10.3390/logistics2020008

Rutten CJ, Velthuis AGJ, Steeneveld W, Hogeveen H (2013) Invited review: Sensors to support health management on dairy farms. J Dairy Sci 96:1928–1952. https://doi.org/10.3168/jds.2012-6107

Sain M, Singh R (2020) Robotic Automation in Dairy and Meat Processing Sector for Hygienic Processing and Enhanced Production. Journal of Community Mobilization and Sustainable Development 15:543–550

Sarkar K, Khajanchi S, Nieto JJ (2020) Modeling and forecasting the COVID-19 pandemic in India. Chaos Solitons Fractals 139. https://doi.org/10.1016/j.chaos.2020.110049

Schoder D (2010) Melamine milk powder and infant formula sold in East Africa. J Food Prot 73:1709–1714. https://doi.org/10.4315/0362-028X-73.9.1709

Schuh G, Rudolf S, Riesener M (2016) Design for industrie 4.0. Proceedings of International Design Conference, DESIGN DS 84:1387–1396

Sepasgozar SME, Shi A, Yang L, Shirowzhan S, Edwards DJ (2020) Additive manufacturing applications for industry 4.0: A systematic critical review. Buildings 10:1–35. https://doi.org/10.3390/buildings10120231

Shabir Barham G, Khaskheli M, Soomro AH, Nizamani ZA (2014) Extent of extraneous water and detection of various adulterants in market milk at Mirpurkhas, Pakistan. Journal of Agriculture and Veterinary Science 7:83–89

Shine P, Murphy MD (2022) Over 20 years of machine learning applications on dairy farms: A comprehensive mapping study. Sensors 22

Shyian N, Moskalenko V, Shabinskyi O, Pechko V (2021) MILK PRICE MODELING AND FORECASTING

Siedliska A, Baranowski P, Zubik M, Mazurek W, Sosnowska B (2018) Detection of fungal infections in strawberry fruit by VNIR/SWIR hyperspectral imaging. Postharvest Biol Technol 139:115–126. https://doi.org/https://doi.org/10.1016/j.postharvbio.2018.01.018

Singuluri H (2014) Milk Adulteration in Hyderabad, India – A Comparative Study on the Levels of Different Adulterants Present in Milk. J Chromatogr Sep Tech 05. https://doi.org/10.4172/2157-7064.1000212

Soomro AA, Khaskheli M, Memon MA, Barham GS, Haq IU, Fazlani N, Ali Khan I, Lochi GM, Soomro RN (2014) Study on adulteration and composition of milk sold at Badin. nternational Journal of Research in Applied, Natural and Social Science 2:57–70

Souza SS, Cruz AG, Walter EHM, Faria JAF, Celeghini RMS, Ferreira MMC, Granato D, Sant'Ana A de S (2011) Monitoring the authenticity of Brazilian UHT milk: A chemometric approach. Food Chem 124:692–695. https://doi.org/10.1016/j.foodchem.2010.06.074

Stone AE (2020) Symposium review: The most important factors affecting adoption of precision dairy monitoring technologies. J Dairy Sci 103:5740–5745. https://doi.org/10.3168/jds.2019-17148

Tang J, Dong T, Li L, Shao L (2018) Intelligent Monitoring System Based on Internet of Things. Wirel Pers Commun 102:1521–1537. https://doi.org/10.1007/s11277-017-5209-9

Upton J, Murphy M, de Boer IJM, Groot Koerkamp PWG, Berentsen PBM, Shalloo L (2015) Investment appraisal of technology innovations on dairy farm electricity consumption. J Dairy Sci 98:898–909. https://doi.org/10.3168/jds.2014-8383

van Asseldonk MAPM, Huirne RBM, Dijkhuizen AA, Beulens AJM (1999) Dynamic programming to determine optimum investments in information technology on dairy farms. Agric Syst 62:17–28. https://doi.org/10.1016/S0308-521X(99)00051-7

Vate-U-Lan P, Quigley D, Masoyras P (2017) Smart Dairy Farming through Internet of Things (Iot). Asian International Journal of Social Sciences 17:23–36. https://doi.org/10.29139/aijss.20170302

Vik J, Stræte EP, Hansen BG, Nærland T (2019) The political robot – The structural consequences of automated milking systems (AMS) in Norway. NJAS - Wageningen Journal of Life Sciences 90–91. https://doi.org/10.1016/j.njas.2019.100305

Virto M, Santamarina-García G, Amores G, Hernández I (2022) Antibiotics in Dairy Production: Where Is the Problem? Dairy 3:541–564. https://doi.org/10.3390/dairy3030039

Wang L, He Y, Wu Z (2022) Design of a Blockchain-Enabled Traceability System Framework for Food Supply Chains. Foods 11:1–18. https://doi.org/10.3390/foods11050744

Wilbey RA (2017) Dairy technology: A UK perspective on its past, present and future. Int J Dairy Technol 70:459–468. https://doi.org/10.1111/1471-0307.12460

Winkelhaus S, Grosse EH (2020) Logistics 4.0: a systematic review towards a new logistics system. Int J Prod Res 58:18–43

Yadav G, Kumar A, Luthra S, Garza-Reyes JA, Kumar V, Batista L (2020) A framework to achieve sustainability in manufacturing organisations of developing economies using industry 4.0 technologies' enablers. Comput Ind 122. https://doi.org/10.1016/j.compind.2020.103280

Yang W, Edwards JP, Eastwood CR, dela Rue BT, Renwick A (2021) Analysis of adoption trends of in-parlor technologies over a 10-year period for labor saving and data capture on pasture-based dairy farms. J Dairy Sci 104:431–442. https://doi.org/10.3168/jds.2020-18726

Zhang A, Heath R, McRobert K, Llewellyn R, Sanderson J, Wiseman L, Rainbow R (2021) Who will benefit from big data? Farmers' perspective on willingness to share farm data. J Rural Stud 88:346–353. https://doi.org/10.1016/j.jrurstud.2021.08.006

Zheng P, Wang H, Sang Z, Zhong RY, Liu Y, Liu C, Mubarok K, Yu S, Xu X (2018) Smart manufacturing systems for Industry 4.0: Conceptual framework, scenarios, and future perspectives. FRONTIERS OF MECHANICAL ENGINEERING 13:137–150. https://doi.org/10.1007/s11465-018-0499-5