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ORIGINAL PAPER

DIGITAL INTEROPERABILITY AND TRANSFORMATION USING INDUSTRY 4.0 TECHNOLOGIES IN THE DAIRY INDUSTRY: AN SLR AND BIBLIOMETRIC ANALYSIS

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ABSTRACT. Background: The dairy industry has gradually adopted cutting-edge technology in the past few years. This review explores the evolution and interventions of Artificial Intelligence (AI), Machine Learning (ML), and Industry 4.0 in the dairy industry through a systematic literature review and bibliometric analysis.
Methods: The Web of Science, Scopus, etc. databases were used for bibliometric analysis from 1999 to 2022 related to the role of technology in the dairy industry. Analysis shows the tremendous growth in technology adoption after 2015, including Industry 4.0, blockchain, and traceability, which have recently emerged in the dairy industry.
Results: The findings suggest that traceability, data management, environmental impacts, and dairy supply chain operations need further exploration. A technological intervention wheel has been generated based on findings from the dairy sector. The current analysis demonstrates that such a bibliometric analysis and a systematic study were previously missing in the dairy industry, especially in a technological context.
Conclusions: This review paves the way for future research on emerging technologies such as traceability, blockchain, and Industry 4.0 in the dairy industry. The impacts of technological intervention on the circular economy and sustainable practices in the dairy industry are a potential area of future research.

Keywords: Dairy industry, Industry 4.0 technologies, Internet-of-things (IoT), Technological interventions, Artificial intelligence (AI)

INTRODUCTION

Technology is crucial in addressing food safety and security issues in different food industry sectors. Inventions and advancing cutting-edge technologies have transformed the food industry in recent decades [Herrero et al., 2020]. Industry 4.0 and AI are the two most important technical aspects driving this revolution. Many other developments affect how AI handles the massive data gathered from IoT devices in real-time. The IoT is the core component in many organizations and industries, enabling and upgrading industries via big data [Hettiarachchi et al., 2022]. Numerous technological advancements have increased the pace of such developments, leading to what is sometimes called the fourth industrial transformation (also known as Industry 4.0), which has digitally changed numerous food industries and the dairy sector. Like other industries, the dairy industry was significantly transformed during the industrial revolution [Malik et al., 2022; Xu et al., 2018]. Industry 4.0 has already intervened in almost every digital, physical, and biological domain [Chapman et al., 2022; Koh et al., 2019; Maynard, 2015]. The existing literature includes "Artificial intelligence (AI), big data (BD), robotics, smart sensors, the Internet of Things (IoT), augmented reality, cybersecurity, and blockchain" technologies in the food industry [Hassoun, Aït-Kaddour, et al., 2022; Hassoun, Bekhit, et al., 2022]. From feed production to animal management, automated milking to milk

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processing, monitoring to planning and dairy optimization, the dairy industry has seen substantial growth in the use of technology. Over the past few decades, the dairy industry has become increasingly saturated, with new customer requirements putting further pressure on and adversely affecting frameworks [Remondino & Zanin, 2022]. The main factors affecting dairy are food life, modernization, population changes, a shift in consumer demand for healthy and customized products, and sustainable standards. The dairy industry still lacks modernization in the context of sustainability [Hopkins & Hawking, 2018; Jayarathna et al., 2021; Pal & Kant, 2019; Zafarzadeh et al., 2021], but it has witnessed technological intervention in the past few years. Currently, industry 4.0 adoption is necessary to optimize the dairy industry for sustainability [Crosson et al., 2010; Gharehyakheh et al., 2020]. The highly perishable nature of dairy products and shifting consumer demand pose serious challenges for the dairy industry in the context of increasing production [Ji et al., 2022]. Emerging technologies are essential to improve safety, quality, and traceability relative to traditional methods of dairy production [Akbar et al., 2020; Burke et al., 2016]. Recently, there has been an increase in the connectivity of dairy industry-specific advancements in technology. There was a dramatic increase in the use of technology during the pandemic [Majumdar et al., 2022]. Such technologies are constantly improving, and more information will be made available to industry. Critical data can enhance system efficiency and animal well-being and longevity [Lovarelli et al., 2020]. The precision livestock sector provides better effectiveness by monitoring animal well-being, production, and environmental impacts, such as carbon emissions and food traceability [Charlebois & Haratifar, 2015; Siddharth et al., 2021; Mor et al., 2021]. However, due to poor coordination between dairy stakeholders and its quantity and complexity, data is not always utilized effectively [Bahlo et al., 2019; Morota et al., 2018; Wolfert et al., 2017].

Furthermore, one important technique is expected to implement a constant process that relies on three states of the value data chain: information gathering, interconnection, and data processing [Chen et al., 2014]. These stages are expected to improve managerial decision-making and accuracy to increase productivity, efficiency, and profitability [Bronson & Knezevic, 2016]. Implementing big data approaches provides more valuable insights than traditional methods [Lioutas et al., 2021]. Industrial intervention in the dairy industry is recognized as essential for improving operational activities, reducing environmental impacts, increasing revenue growth, and introducing sustainable techniques [Cabrera & Fadul-Pacheco, 2021; Etherington et al., 1995].

This review paper includes a systematic and bibliometric analysis of the existing literature discussing the intervention of technologies such as AI and Industry 4.0 in the dairy industry. Section 2 briefly outlines the review methodology adopted by authors to conduct this review; section 3 features a descriptive analysis of existing literature related to the theme; section 4 provides the bibliometric analysis; and section 5 discusses the review findings critically, along with some potential technological interventions and challenges in the dairy industry. Future research directions are discussed in the conclusion.

REVIEW METHODOLOGY

There is significant information in scientific databases, but scholars, policy experts, and professionals cannot always access it. For researchers and policymakers, obtaining valuable information from these databases takes time [Jamwal et al., 2021]. Systematic and bibliographic approaches were used to address the research questions of this paper. In line with the suggestions of Denyer and Tranfield [2009], a five-phase process was used for this systematic review, which includes review planning, database selection, inclusion/exclusion criteria, analysis and synthesis, and review reporting, as shown in Figure 1.

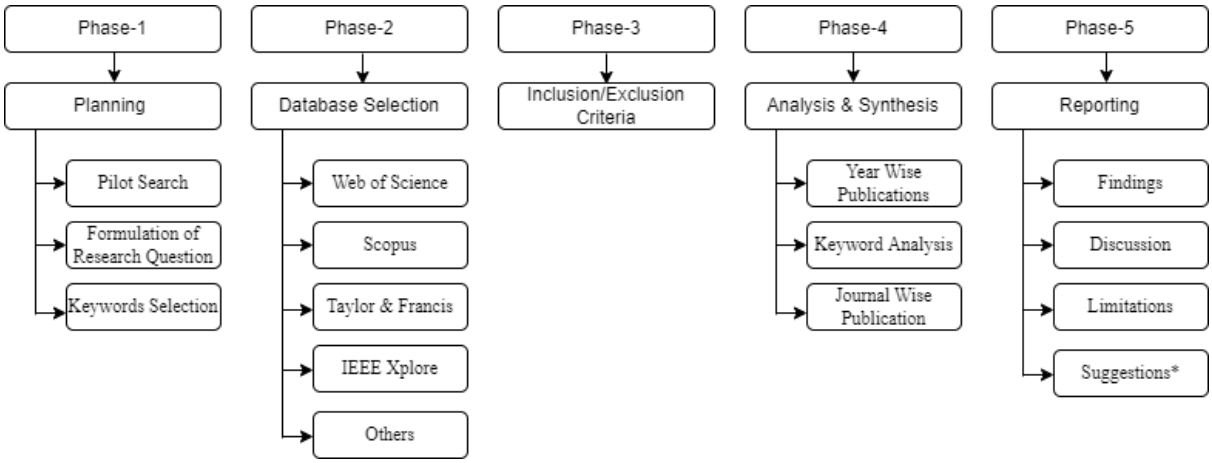

Fig. 1. Systematic review approach.

Planning Phase

As part of the review planning phase, the authors conducted a pilot search to understand the existing literature better and define inclusion/exclusion criteria. The primary goal of a systematic review is to properly formulate the research question, which leads to the selection of appropriate articles. The formulation of a research question, the selection of keywords, the selection of a database, and the use of well-defined inclusion/exclusion criteria all contribute to the flow of a systematic review. The main objective of this review is to explore the technological role of AI and Industry 4.0 in the dairy industry. The following research questions were formulated based on this review theme: 1) to explore the technological interventions of Industry 4.0 and digital technologies in the dairy industry; 2) to identify the interconnection between the dairy industry and Industry 4.0 or digital technologies.

The goal of research question 1 is to examine the existing literature to determine which technologies based on AI and IoT are used in the dairy industry. The second research question identifies the benefits of technologies, challenges, and future directions that will assist practitioners and researchers alike. The authors searched for articles in various scientific databases using the keywords “dairy industry,” “AI,” “IoT,” “dairy,” and “Industry 4.0.” The search queries ("industry 4.0" OR "artificial intelligence" OR "Blockchain" OR "Internet of things" OR "IoT" OR "machine learning") and ("dairy industry" OR "dairy") were used.

Selection of databases and keywords

The authors searched for relevant studies in various databases in the second phase. The authors selected Web of Science, Scopus, IEEE Xplore, Taylor & Francis, Wiley, and other reputable databases. The authors also used snowballing and back-referencing to select some articles. Databases were searched by adding search strings to the title, abstract, and keywords sections. The authors used the following keywords: Industry 4.0, the dairy industry, digital technology, and AI.

Inclusion/Exclusion criteria

The authors included articles related to technologies focused on the dairy industry. Only articles published in English and whose full text was available were considered for review. The authors only considered articles on technological intervention and adoption in the dairy industry.

Analysis and Synthesis/analysis method or tool used

Initially, the authors retrieved 571 articles from the selected databases. After applying the inclusion and exclusion criteria, which included full access, 376 articles were identified. The screening revealed that some articles were duplicates, and some were unrelated to the dairy industry or technological interventions, leaving

only 102 articles for the final review and analysis. Descriptive statistics were used to analyze the literature. VOS Viewer and Biblioshiny library in R-studio were used for bibliographic analysis (both software applications are open access). The Biblioshiny library was used in R studio for word analysis, trends analysis, and to generate a thematic map. Vosviewer was used to analyze the co-occurrence of keywords and for cluster analysis.

RESULTS

Descriptive Statistics

This analysis aims to present the most relevant features of the selected literature, focusing on aspects related to the technological intervention of AI and Industry 4.0 in the dairy industry. The aspects considered are the latest trends related to technology in research publications, the evolution of technological intervention in the dairy industry, annual publications on related themes, the types of articles, and the journals that most frequently published articles on these topics.

Trends of publication time

Technological interventions involving AI and Industry 4.0 have been observed recently in the dairy industry. Figure 2 shows the trend in publications in the dairy industry over the past few years. Significant growth in the dairy industry can be seen after 2015, especially in the technological context. The trend indicates the increasing attention of industries and researchers toward digitalization in the dairy industry by using Industry 4.0 and digital technologies.

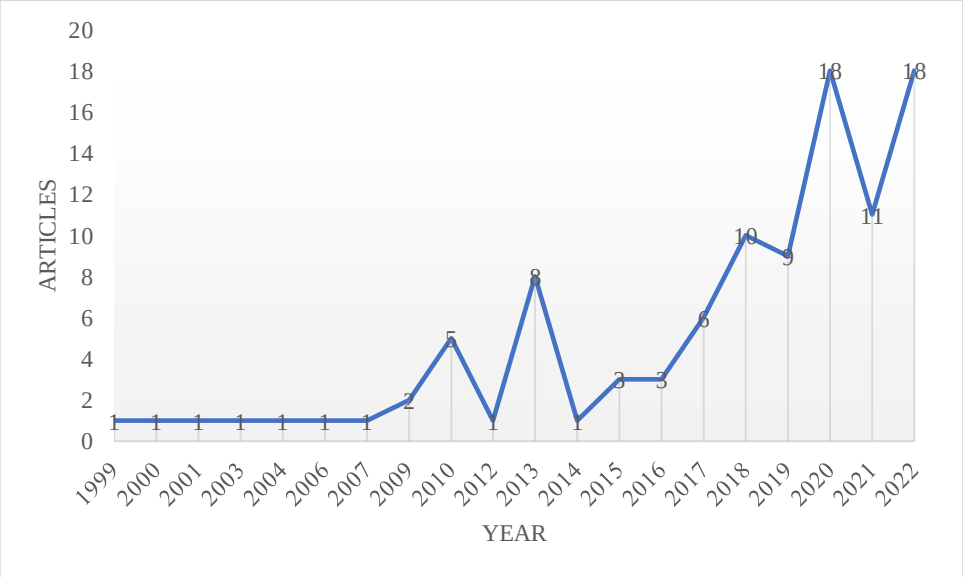

Fig. 2. Trends related to technology in research publications.

The number of publications is directly proportional to the increasing interest of researchers in emerging research areas related to technologies for various tasks, such as safety, security, efficiency, and management.

Evolution of Industry 4.0 technologies in the dairy industry

This analysis indicates the trend in the dairy industry's usage or implementation of different Industry 4.0 and digital technologies. Figure 3 depicts the evolution of Industry 4.0 and digital technologies and reveals a distinguishable increase in technological adoption after 2007. Since 2015, there has been an exponential increase in the adoption of these technologies. Among others, Industry 4.0 and Blockchain technology are dominant.

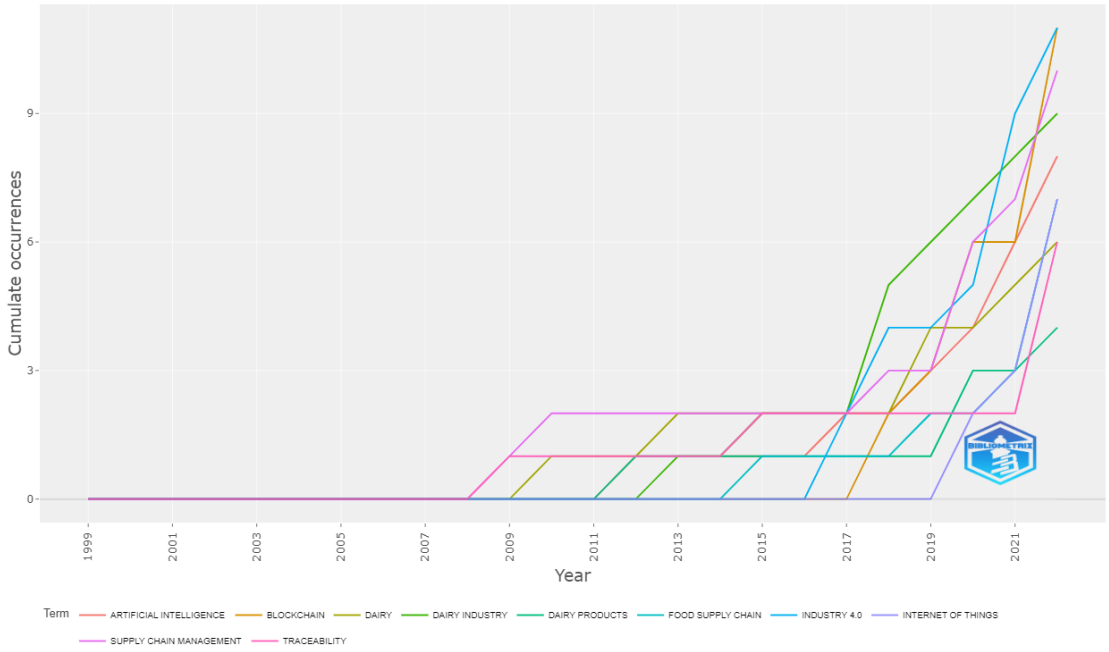

Fig. 3. Growth in technology adoption in the dairy industry.

Figure 3 depicts the cumulative occurrence of the most commonly used keywords in the recent literature, such as Industry 4.0, Blockchain, AI, the dairy industry, and traceability. It indicates that researchers are becoming more interested in technological applications in the dairy sector.

Journals that featured the most articles

The selected articles were published in 66 different journals. Figure 4 shows the journals that featured the most publications. Overall, the *Journal of Dairy Science* featured the most articles related to the research theme (only the top journals are listed).

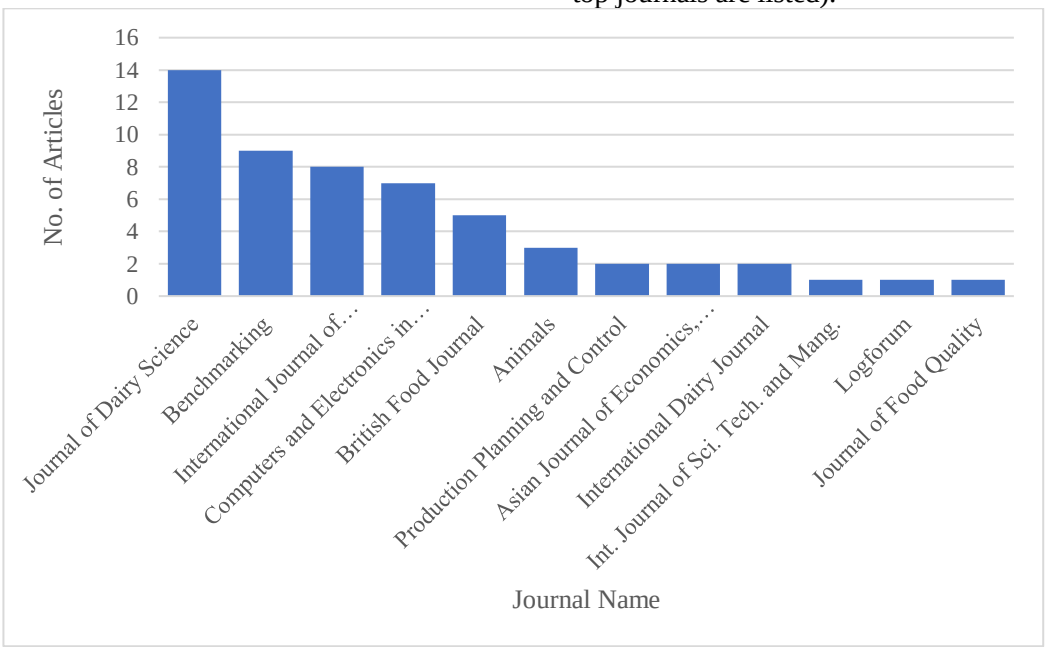

Fig. 4. Journals featuring the most articles on the research theme.

Benchmarking, the *International Journal of Production Research* and *Computers and Electronics in Agriculture* are leading journals with publications related to technological applications in the dairy industry.

Bibliometric Analysis

This section explores the most common themes discussed in the articles selected for the review. The authors analyzed the keywords used by the authors in the selected articles. This analysis focuses on the main themes related to technological interventions in the dairy industry and points toward the most used keywords. In previous research, researchers used different software applications for bibliometric analysis, each with its benefits and drawbacks [Jamwal et al., 2022].

Keywords co-occurrence

The co-occurrence of the keywords in the selected research articles is closely related to the theme of the review. Figure 5 shows the keyword analysis; this distribution demonstrates the popularity of various technological interventions in the dairy industry.

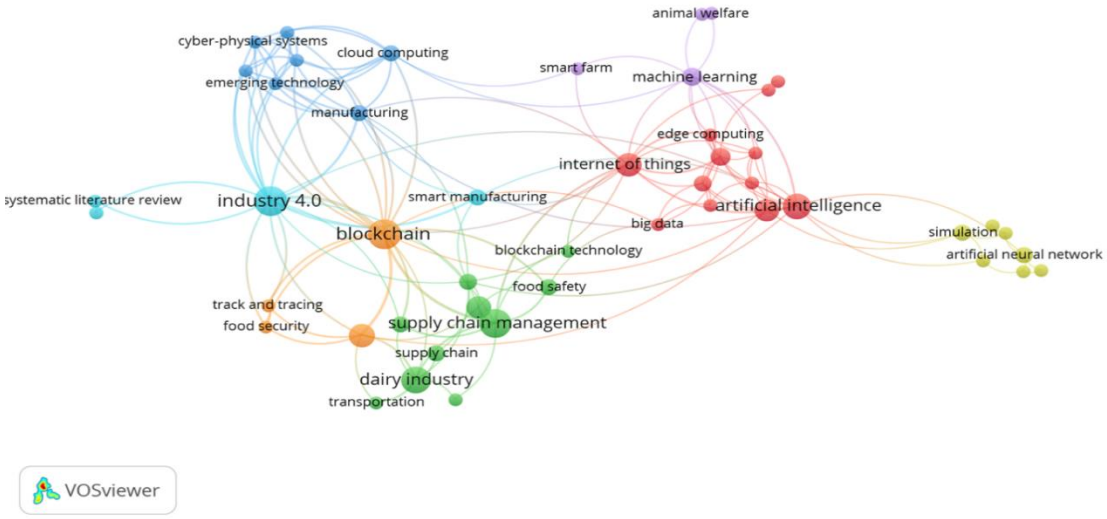

Fig. 5. Network of keywords analysis.

As shown in Figure 5, the "Industry 4.0" keyword is strongly associated with "blockchain," which is further strongly linked with "dairy industry" and "supply chain management." The keyword "Internet of Things" is strongly associated with "AI" and "machine learning." Industry 4.0, Blockchain, AI, and the dairy industry are the most prominent keywords in Figure 5.

Thematic Map Analysis

Figure 6 shows four quadrants: niche themes, motor themes, emerging or declining themes, and basic themes. Density and centrality parameters were used to characterize these themes. The importance of a given theme in the entire domain is represented by centrality, and its development or growth is measured by density [Cobo et al., 2011]. Each quadrant represents a different aspect related to the evolution of a given technology. The emerging or declining themes quadrant shows the deficient development of a theme in a given domain; simulation appears in this quadrant, indicating its relatively modest applicability in the dairy industry. Motor themes represent all the properly established themes in the given domain that are essential from a research point of view. Smart farms, artificial neural networks (ANN), AI, ML, and blockchain appear in this quadrant, which indicates their potential application in the dairy industry.

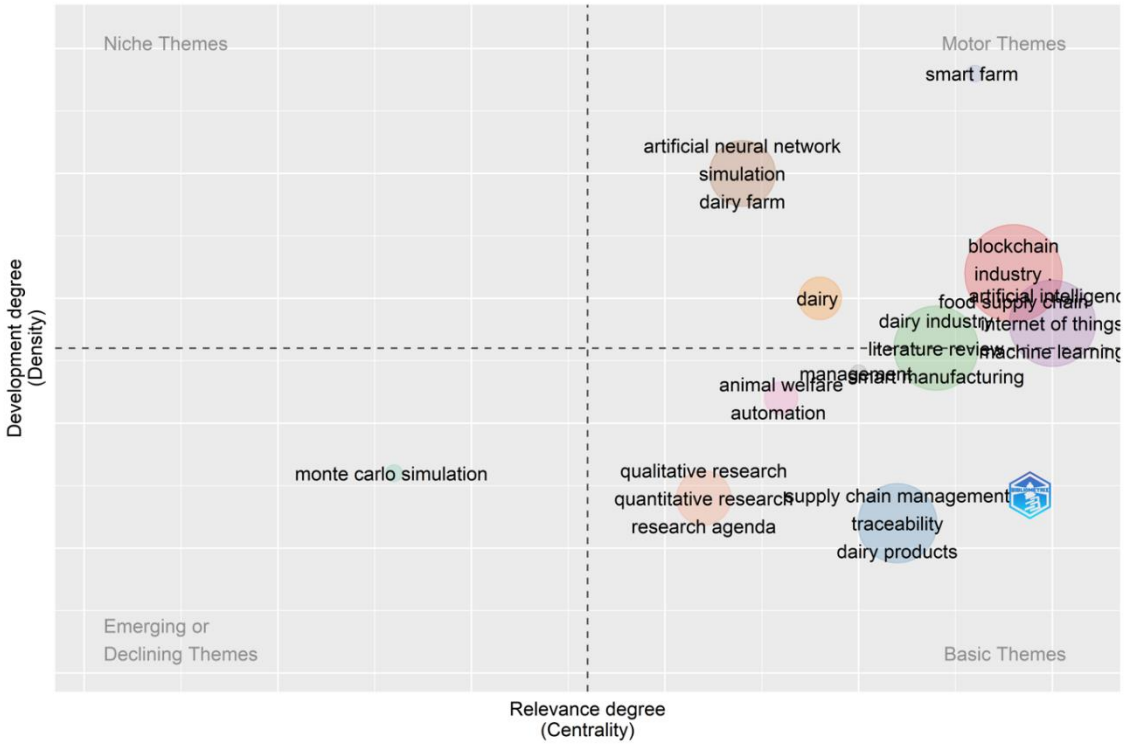

Fig. 6. Thematic analysis.

The basic theme quadrant features clusters essential to the given research field, which still need to be implemented and explored from a research point of view. The dairy industry still underutilizes traceability, automation, optimized supply chain management, and animal welfare.

Cluster analysis

Figure 5 presents seven clusters in the keyword network diagram represented by seven colors. Based on their connections, the authors categorize the keywords into seven clusters. Table 1 shows the seven identified clusters and the keywords associated with each cluster.

Although there were seven clusters, the authors merged clusters 2 and 7 as these both indicate the intervention of blockchain technology in the food safety and security context in the dairy industry.

1. The red cluster includes twelve keywords: AI, big data, the IoT, sensors, etc. These keywords indicate that this cluster's main topic is the exploration of digital interventions in the dairy industry.
2. The green and orange clusters include ten and four keywords, including blockchain technology, dairy industry, traceability, food safety, etc. These keywords indicate that the main topic of these clusters is the exploration of technological interventions in the context of traceability and food safety in the dairy industry.
3. The blue cluster includes seven keywords: cyber-physical system, cloud computation, industrial integration, IoT, etc. These keywords indicate that the main topic of this cluster is the exploration of technological interventions in the context of the industrial integration of technologies within the dairy industry.
4. The yellow cluster includes seven keywords: prediction, optimization, artificial neural network, dairy farms, etc. These keywords indicate that the main topic of this cluster is the exploration of industrial optimization in the dairy industry.

5. The purple cluster includes four keywords: animal welfare, automation, machine learning, and smart farms. These keywords indicate that the main topic of this cluster is the exploration of technological interventions in production and livestock cattle management in the dairy industry.
6. The light blue cluster includes four keywords: Industry 4.0, smart manufacturing, the fourth industrial revolution, and systematic review. These keywords indicate that the main topic of this cluster is the systematic exploration of technological interventions in the dairy industry in a manufacturing context.

Table 1. Clusters and associated keywords

No. of Cluster	List of Keywords
Cluster 1	• Artificial intelligence • Big data • Dairy • Data integration • Data Sharing • Edge computing • Internet of things • Management • Precision agriculture • Precision livestock farm • Sensors • Smart farming
Cluster 2	• Blockchain technology • Dairy industry • Decision making • Food safety • Smart contracts • Supply chain • Supply chain management • Sustainability • traceability
Cluster 3	• Cloud computing • Cyber-physical systems • Emerging technology • Industrial integration • Industrie 4.0 • IoT • Manufacturing
Cluster 4	• Artificial neural network • Dairy farm • Milk production • Modeling • Optimization • Prediction • Simulation
Cluster 5	• Animal welfare • Automation • Machine learning • Smart farm
Cluster 6	• Industry 4.0 • Smart manufacturing • Systematic literature review • Fourth industrial revolution
Cluster 7	• Blockchain • Food security • Food supply chain • Track and tracing

DISCUSSION

Based on the seven clusters, the identified technologies in each cluster and their respective applications in the dairy industry are categorized in Table 2, which includes technological interventions based on all the discussed technologies in different areas of the dairy industry.

Table 2. Technological Interventions of Industry 4.0 and Digital Technologies

Themes	Identified Technologies	Applications	References
Cluster 1	• Artificial intelligence • Big data • Data integration • Edge computing • Internet of things	• Improved data management • Profit maximization • Cost Minimization • Data integration • Animal welfare • Real-time monitoring • Real-time data collection • Prediction • Smart framing	[Aamer et al., 2021; Cabrera et al., 2020; Chander et al., 2022; da Rosa Righi et al., 2020; Fuentes et al., 2020; Goli et al., 2019, 2021; Khademi, 2018; Michie et al., 2020; Newton et al., 2020; Rebelo et al., 2022; Satya & Chimakurthi, 2017; Zhou et al., 2022]
Clusters 2 & 7	• Blockchain technology • Smart contracts • traceability	• Data security • Data integrity • Food safety • Food Security • Transparency • Decentralized system • Increased visibility • Increased accountability • Direct supply chain management • Traceable supply chain • Smart decision making	[Casino et al., 2020; Cavite et al., 2022; Kasten, 2019; Kayikci et al., 2022; Khan et al., 2022; Khanna et al., 2022; Kher et al., 2010; Kumar & Kumar, 2020; Lee et al., 2013; León-Bravo et al., 2022; Mania et al., 2018; Manikas & Manos, 2009; Niya et al., 2021; Shingh et al., 2020; Srivastava & Dashora, 2022; Tan & Ngan, 2020; Varavallo et al., 2022; Yi et al., 2022; Zhou et al., 2022]
Cluster 3	• Cloud computing • Cyber-physical systems • Industrial integration • Industry 4.0 • IoT	• Data sharing • Product sorting • Product identification • Product handling • Monitoring • Animal health monitoring • Alerts • Automated packaging • Robotics	[Akbar et al., 2020; Alonso et al., 2020; Deshmukh & Kele, 2015; Jachimczyk et al., 2021; Jamwal, Agrawal, Sharma, & Giallanza, 2021; Kayikci et al., 2022; Liao et al., 2017; Xu et al., 2018; Zheng et al., 2021]
Cluster 4	• Artificial neural network • Modeling • Optimization • Prediction • Simulation	• Process optimization • Process simulations • Demand forecasting • Predictive maintenance • Cost and profit optimization • Route Planning	[Chaturvedi et al., 2013; da Rosa Righi et al., 2020; Dash et al., 2022; Fadul-Pacheco et al., 2021; Goli et al., 2019; Goyal & Goyal, 2012; Hosseinzadeh-Bandbafha et al., 2018; Kebreab et al., 2019; Khademi, 2018; Macciotta et al., 2000; Schulze et al., 2007; Sefeedpari et al., 2013; Shokri Dariyan et al., 2020]
Cluster 5	• Animal welfare • Automation • Machine learning	• Automatic milking • Automated feeding • Automated handling • Classification and sorting • Prediction • Animal monitoring • Diseases control • Behavior analysis	[Cockburn, 2020; Fadul-Pacheco et al., 2021; Gengler, 2019; Ji et al., 2022; Michie et al., 2020; Shine & Murphy, 2022; Taneja et al., 2020; Warner et al., 2020]
Cluster 6	• Industry 4.0 • Smart manufacturing	• Smart production • Systematic processes • Inventory management • Real-time analysis • Improved efficiency • Waste management • Smart sensing • Re-productions	[Borah, 2017; Cannas et al., 2020; Charlebois & Haratifar, 2015; Cleary et al., 1999; Crosson et al., 2010; Daftary, 2019; Fadul-Pacheco et al., 2022; Geary et al., 2010; Georgiadis et al., 2019; Khanal et al., 2010; Liberati & Zappavigna, 2009; Maldonado-Siman et al., 2013; Mor et al., 2018a, 2018b; Rutten et al., 2013; Sel et al., 2017; S. Sharma et al., 2021; Y. K. Sharma et al., 2019; St-Pierre & Jones, 2001]

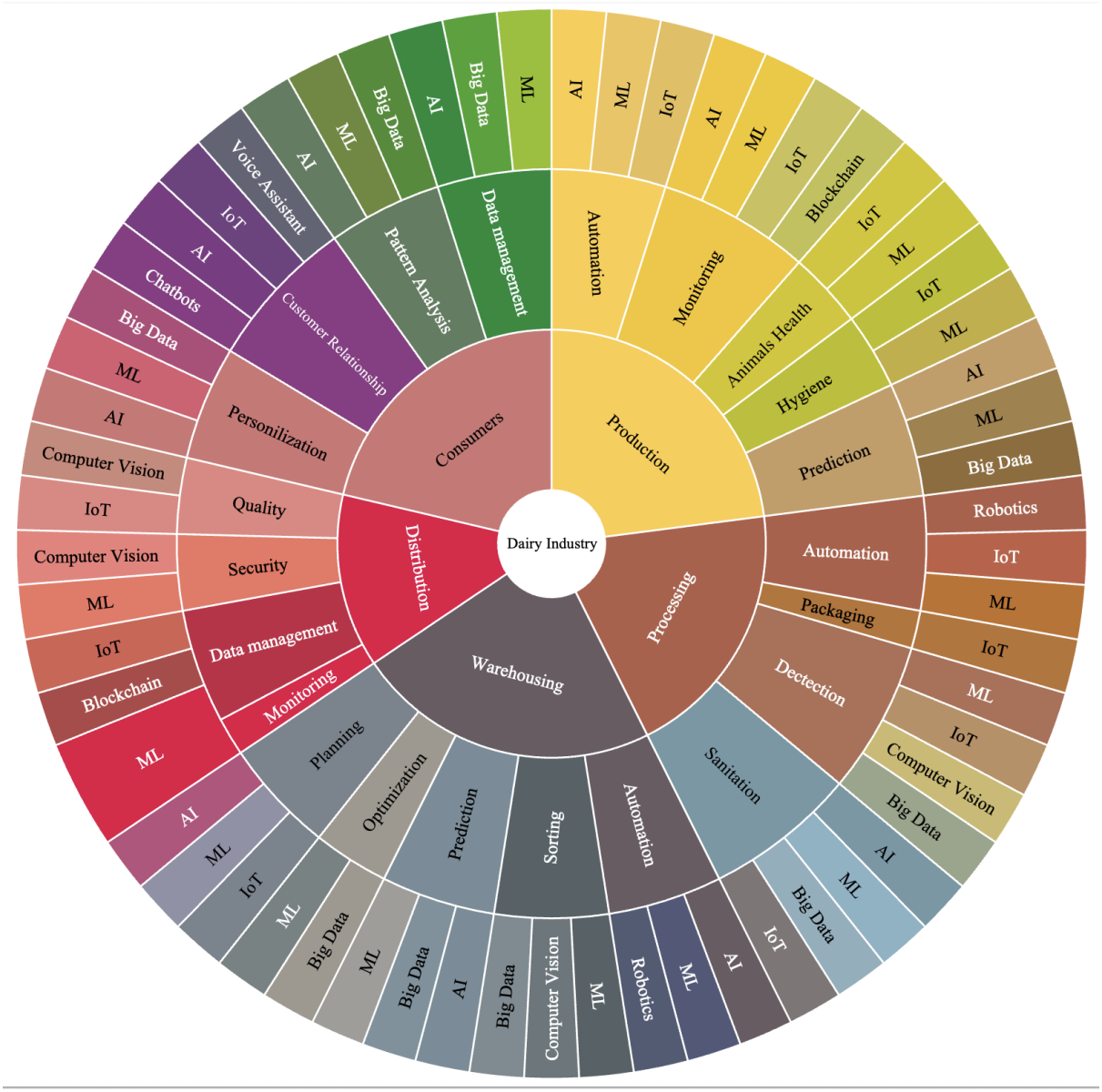

Fig. 7. Potential applications of technological adoption in the dairy industry.

Figure 7 provides a breakdown of dairy industry operations in different domains and the potential applications of Industry 4.0 technologies from farm to fork. Despite several applications, there are also drawbacks one should be aware of. The role of Industry 4.0 technology in sustainable practices in the dairy industry is still unexplored [Jamwal, Agrawal, Sharma, & Giallanza, 2021]. The same applies to other ingenious and intelligent technologies. It is well known that IoT and AI improve security measures but also introduce some flaws. Cyber-security is a risk for both beginners and professionals. Too much connectivity, mainly through IoT, can lay the groundwork for data leakage, loss of data, and hardware/network-based attacks. A second significant issue is technical complexity. These technologies involve many technical details that are challenging for the average employee to understand. Any power failure or software problem can cause the entire network to go down, generating substantial losses because the

entire system is connected to its network by IoT devices. Industries have started using connected technologies to replace employees due to the growth and popularity of technology, which can lead to fewer job opportunities.

CONCLUSION

This review focused on technological interventions in the dairy industry, an emerging research domain. The status of the digital revolution in the dairy industry has been examined using a systematic and bibliographic approach. The authors conducted a bibliometric analysis of technological interventions in the dairy industry by selecting 102 articles published from 1999 to 2022. They utilized R studio, Microsoft Excel, and VOSviewer to generate informative statistics to analyze technological interventions in the dairy industry. Keyword analysis showed that Industry 4.0, blockchain, and AI were the most used keywords in the dairy industry. The review findings demonstrate the evolution of technology in the dairy industry, indicating the contribution of Industry 4.0.

The cluster analysis of potential technological applications within the dairy industry categorized them into different areas. The outcomes also indicate considerable scope for technological adoption on a larger scale to overcome the challenges related to food safety, security, and sustainability. The analysis, including traceability, animal welfare, and supply chain management, illustrated several promising research pathways. Further, this study can be extended domain-wise in the dairy industry to explore the most used technologies, such as Blockchain, IoT, and others, to address food safety, quality, and traceability-related issues.

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