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Reviewing the transition from industry 1.0 to industry 5.0 in the food processing industry

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Abstract

The transition of the food processing sector from Industry 1.0 to Industry 5.0 represents a notable shift towards adopting integrated and multidisciplinary approaches that emphasise the well-being of humans, resilience, and sustainability of digital technology. Industry 4.0 focused on enhancing the profitability and efficiency of food processing via the use of digitalization and automation. On the other hand, Industry 5.0 aims to facilitate extensive cooperation between humans and robots, optimizing human capabilities using advanced technologies such as Big Data, AI, and IoT. This study presents a thorough examination of the evolution of industrial revolutions in the food processing industry, with a particular emphasis on the impacts of various phases of industrialization on food production, quality assurance, and sustainability. The study has employed three approaches viz. descriptive analysis to analyse key trends, keywords and their growth rate; thematic analysis to determine the current development and interdisciplinary state of the industrial revolutions and systematic literature review to gain an overall comprehensive understanding of transition in between industrial revolutions. It highlights the substantial influence of technology in improving operational efficiency. It also examines the developing concepts and patterns in Industry 5.0, such as design focused on human needs, enhanced personalization, and environmentally friendly practices. The study provides useful insights into the current condition and future direction of the food processing industry's growth in the era of Industry 5.0

Keywords: Industry 1.0, Industry 2.0, Industry 3.0, Industry 4.0, Industry 5.0, transition, current status, systematic review

1. Introduction

The evolution of Industry 5.0 from Industry 1.0 in the food processing sector signifies a notable transition towards inclusive and multidisciplinary approaches. The most recent Industry 4.0 places a high emphasis on maximizing profitability and efficiency via digitalization and automation (Hassoun, 2024) ^[18]. While, Industry 5.0 prioritizes human-centeredness, enhancing the sustainability and resilience of food production while fostering robust cooperation between people and robots in the food and agricultural sector (Hassoun, 2024; Sarioğlu, 2023) ^[18, 41]. This transformation involves using cutting-edge technologies like Big Data, Artificial Intelligence (AI), and the Internet of Things (IoT) to optimize human capabilities and improve outcomes (Tyagi *et al.*, 2023) ^[46].

The preparation of food has been significantly influenced by technological improvements over various industrial periods. In the first phase of the Industrial Revolution, conventional nutritional studies focused on the promotion of health and preventive medicine. Contemporary lifestyles have led to the emergence of sustainable methods for making packaged food, such as fermentation and enzyme processing (Pattabhiramaiah & Mallikarjunaiah, 2023) ^[33]. The introduction of image processing technology has greatly transformed the fields of quality control, defect detection, and food grading during the transition to Industry 2.0. As a result, there has been a rise in operational efficiency and enhanced consumer safety (Mounika *et al.*, 2024) ^[29].

During the period marked by Industry 3.0, the introduction of AI brought about a significant transformation in the food processing business by using data-driven decision-making, AI-enhanced quality control and tailored nutrition recommendations. As a result, there were improvements in production and distribution methods, with a simultaneous focus on promoting sustainability (Wilson *et al.*, 2024) ^[49]. Despite the early financial constraints, AI-driven solutions remain vital in addressing consumer health issues and improving food processing procedures in the era of advanced technology and innovation (Payal *et al.*, 2024) ^[34]. Industry 4.0 and Industry 5.0 represent significant phases in the evolution of industrial practices, with each phase distinguished by specific characteristics and goals. Industry 4.0 focuses on the integration of automation and data exchange through the application of technologies including IoT and AI. Industry 5.0 emphasizes the synergy between human operators and machines, prioritizing sustainability and customized manufacturing processes. Industry 4.0 is characterized by the integration of smart factories and automation technologies. This paradigm shift promised enhanced productivity through the utilization of advanced technologies (Kumar *et al.*, 2024) ^[22]. The methodology primarily relies on technology-driven processes, often reducing human involvement in production (Prabhu *et al.*, 2023) ^[35].

Industry 5.0 seeks to integrate human creativity with advanced machinery, fostering a collaborative environment

(Borchardt *et al.*, 2022; Rajkumar *et al.*, 2024; Mulongo, 2024) [8, 30, 36]. Prabhu *et al.* (2023) [35] analysed the limitations of Industry 4.0, highlighting the significance of sustainability and social responsibility, in alignment with the UN's Sustainable Development Goals. The fifth industrial revolution enables mass customization and enhances customer satisfaction through the provision of tailored products (Varshney & Singhal *et al.*, 2024) [47]. Furthermore, the adoption of Industry 5.0 technologies, such as digital twins, cobots, and mass customisation, might lead to a novel marketing strategy defined by mass customization and the emergence of a "consumer 5.0" (Sarioğlu, 2023) [41]. Utilizing a range of advanced information and communication technologies (ICTs) such as blockchain, artificial intelligence, and digital twins has the potential to greatly enhance the sustainability and resilience of the food system, especially during catastrophes like the COVID-19 pandemic (Guruswamy *et al.*, 2022) [15]. The advancements associated with Industry 5.0 are considerable; nonetheless, the extent of its adoption remains insufficiently examined. This situation underscores the need for further research and the formulation of effective implementation strategies (Mulongo, 2024) [30].

The review of existing literature identified gaps such as lack of identification of notable trends and keywords, current development within industrial revolutions and an overall comprehensive understanding of the current status of the industrial revolutions. So, to understand the industrial revolutions, academic research published from 2018 to 2024 in the Scopus database is shortlisted to identify evolving themes, trends, keywords and current developments within the industrial revolution. The objectives and methods of data collection are discussed in the upcoming section. Further, descriptive analysis, thematic mapping and systematic review are presented so that the current status of transformation from one industrial revolution to another can be achieved.

2. Methodology

2.1 Review Objectives

- To understand the transformation from one industrial revolution to another, the study focussed on three major objectives viz.:
- To determine the notable trends, keywords and growth rate of transition from Industry 1.0 to Industry 5.0 in the food processing industry.
- To analyse the current development and interdisciplinary state of transition from Industry 1.0 to Industry 5.0 in the food processing industry.
- To provide a comprehensive understanding for assessing the current status of the transition from Industry 1.0 to Industry 5.0.

2.2 Data Collection

To assess the transition from Industry 1.0 to Industry 5.0 in the food processing industry, the study utilised a wide range of publications available in Scopus database. The data collection period spanned from January 2018 to June 2024, and extracted around 5,578 documents related to Industry 1.0 to 5.0 on Scopus database. The selected time range was designed to include recent advancements and accurately depict the present transition towards Industry 5.0, providing

a comprehensive overview of the industry's developments. The database was sorted by selecting specific keywords related to the food processing industry, including "Industry 1.0", "Industry 1.0 in food processing", "Industry 2.0", "Industry 2.0 evolution," "Industry 3.0", "Industry 3.0 advancements," "Industry 4.0", "Industry 4.0 technologies," "Industry 5.0", "Industry 5.0 integration," "food processing automation," "digital transformation in food industry," and "sustainability in food processing," "Cobots," "Augmented Reality", "AI", "IoT," "Big data", "Virtual Reality", which resulted into sorting out 907 papers. The list was further narrowed down with subject area of research viz food business and management. The total papers after this step were 136 papers which were analysed using Biblioshiny software for carrying out descriptive and thematic analysis. Further, for carrying out systematic literature review, the 136 paper were further assessed to be categorised into 4 broad themes i.e. literature review of transformation from industry 1.0 to industry 4.0, review of transformation to industry 4.0 and its status, evolutionary change in transformation from industry 4.0 to 5.0 and transformation to industry 5.0 and its role. This approach further narrowed down the papers to 26 number. A total of 26 papers were then further reviewed systematically.

2.3 Criteria for Inclusion and Exclusion of Data

Inclusion Criteria

- Research papers, review papers, conference papers, and books related to the current status of the transition from Industry 1.0 to Industry 5.0.
- Papers published from 2018 to June 2024.
- Relevant sources like Scopus are used.

Exclusion Criteria

- Predatory Journals are excluded.
- Papers published before 2018.
- Papers from predatory sources and journals are avoided.

2.4 Data Analysis Tools and Techniques

To analyse the data on the transition from Industry 1.0 to Industry 5.0 in food processing, a combination of descriptive and thematic analysis was conducted using Biblioshiny as a tool with R programming language (Madhavan *et al.*, 2022) [27]. This tool enabled a thorough examination of publication trends, the frequency of keywords appearing together, and the evolution of study themes over a while. The data for this study was effectively and efficiently gathered from reputable sources like Scopus and other pertinent databases. This was conducted to provide a comprehensive and reliable foundation for the analysis.

For conducting the systematic literature review, a thorough literature study was conducted to systematically locate, evaluate, and incorporate the existing research on the transition between various stages of food processing in the industrial revolutions (Knorr *et al.*, 2020) [20]. This included using a thorough search strategy, conducting a meticulous assessment of the chosen study, and extracting pertinent data to get a full comprehension of the industry's progress (Ghoshal, 2018) [13]. The descriptive study produced quantitative data about publishing metrics, while the thematic analysis uncovered notable patterns and themes in

the literature, offering a detailed understanding of the progression of food processing from Industry 1.0 to Industry 5.0 (Formunyam, 2020) ^[12]. This rigorous methodology ensured that the study was founded on a robust and dependable methodological framework, including the complexities and advancements within all five industrial revolutions (Hassoun *et al.*, 2022) ^[16].

3. Descriptive Analysis of Current Status

The transition from Industry 1.0 to Industry 5.0 in food processing necessitates a comprehensive examination to understand the evolving interplay between technology and human collaboration. This analysis is critical for recognising current challenges, opportunities, and implications related to the incorporation of advanced technologies in food production.

Understanding Industry 5.0: Industry 5.0 emphasizes the collaboration between humans and machines, to enhance productivity and sustainability in the food processing sector (Mulongo, 2024) ^[30]. This method improves Industry 4.0 by incorporating advanced technologies, including artificial intelligence, robotics, and the Internet of Things, which are essential for modernizing food production systems.

Identification and Resolution of Issues: The transition requires the identification and resolution of challenges such as data privacy, cybersecurity, and equitable access to technology, particularly for small-scale producers (Demircioğlu *et al.*, 2024). A descriptive analysis aids in recognizing these barriers and developing strategies for effective implementation (Mulongo, 2024) ^[30].

Enhancing Operational Efficiency: The incorporation of machine learning and deep learning in Industry 5.0 enables the optimisation of production processes, enhances energy efficiency, and improves product quality (Goswami *et al.*, 2024) ^[14].

Technological advancements are of significant importance, however, it is equally necessary to assess the ethical and societal implications associated with these developments. This evaluation guarantees that the shift to Industry 5.0 is characterized by inclusivity and sustainability.

3.1 Annual Scientific Production

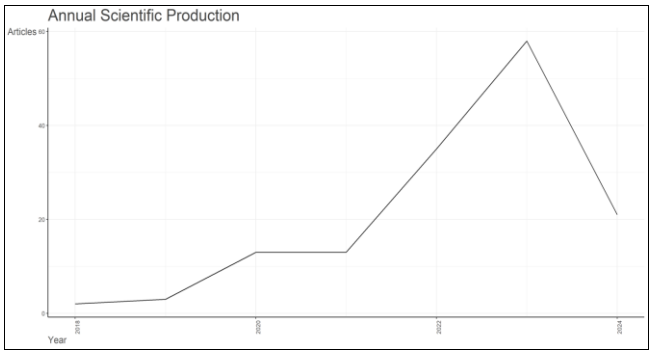


Fig 1: Annual Scientific Production

The annual scientific production on the transition from Industry 1.0 to Industry 5.0 in food processing shows

significant growth from 2018 to 2024, reflecting the increasing scholarly focus on this area. In 2018, the number of published papers was restricted to two. However, it saw a consistent increase to 3 in 2019. In 2020, there was a significant rise, with a cumulative 13 articles produced, and this figure remained unchanged in 2021. In 2022, there was a substantial surge of 35 articles, and in 2023, there was an even more pronounced expansion, reaching a total of 58 papers. Although the number of publications decreased to 21 in 2024, the overall trend indicates a greater focus on this topic.

An analysis of the number of citations provided by each item provides further insight into the impact of the research. In 2018, the average number of citations per article was 37.5. Over 7 years, the articles were eligible for citation and received an average of 5.36 citations per year. In 2019, the citation rate peaked at an average of 73 citations per article and 12.17 citations per year during 6 years. This signifies the existence of very prominent publications during this period. Subsequently, there was an increase in the quantity of publications in the subsequent years. Nevertheless, there was a discrepancy in the average number of citations per piece, with 26.77 in 2020 and 26.92 in 2021. The mean annual citation count was 5.35 and 6.73, respectively. The rise in the quantity of articles in 2022 and 2023 led to a decline in the average number of citations per article (13.09 and 8.86), suggesting that recent publications are still being referenced. By 2024, the average citation rate per article had a significant decline, reaching a value of 0.38. The decline in citations may be ascribed to the recent publication of these publications and their short duration for potential citations.

This data illustrates a vibrant and expanding research landscape, with increasing contributions and varied citation impacts that demonstrate the originality and ongoing integration of Industry 5.0 principles in food processing. This comprehensive examination of annual scientific production highlights the evolving focus of the business, demonstrating how the academic community has adjusted to changing industrial paradigms.

3.2 Top Search of Transition from Industry 1.0 to Industry 5.0

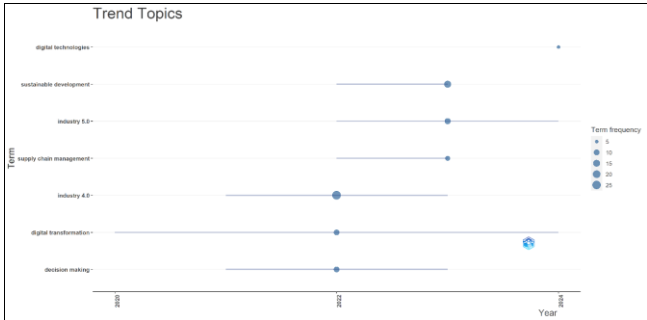


Fig 2: Trend Topics

An analysis of the shift from Industry 1.0 to Industry 5.0 in the food processing sector reveals notable trends. The prominence of decision-making processes has been particularly emphasized, with significant engagement seen in 2021, peaking in 2022, and continuing until 2023. The

integration of digital technology has been a primary focal point, with a notable emphasis expected in 2024. Starting from 2020, there has been an increasing acknowledgement of the significant influence of digital transformation, which is projected to continue gathering strength until 2024. Between 2021 and 2023, Industry 4.0 technologies, namely smart manufacturing and automation, have consistently had a substantial impact. Industry 5.0 is defined by a shift towards more collaboration between people and robots, along with an emphasis on sustainability. This phenomenon has garnered much scrutiny from 2022 to 2024. The area of supply chain management has continually maintained its significance in both 2022 and 2023, highlighting its continuing importance. Moreover, sustainable development has become a major and increasingly crucial trend in the business, attracting increased attention in 2022 and 2023. To summarize, the examination of patterns indicates a total of 87 noteworthy mentions. The first observations started in 14152, with the median points documented at 14159, and the following observations continued until 14164.

3.3 Mapping the Keywords and Growth Rate



Fig 3: Word Cloud

An extensive investigation of the transition from Industry 1.0 to Industry 5.0 in the domain of food processing included a thorough investigation of keywords and their rates of advancement. This research did a descriptive analysis to analyze the frequency of certain terms and their variations between 2018 and mid-2024, using data. The phrases that were examined include "Industry 4.0," "sustainable development," "Industry 5.0," "decision making," "digital transformation," "supply chain management," "supply chains," "circular economy," "digitalization," and "competition." The data collected from sources such as Scopus, Wiley, Google Scholar, and MDPI were methodically acquired and carefully and thoroughly analysed.

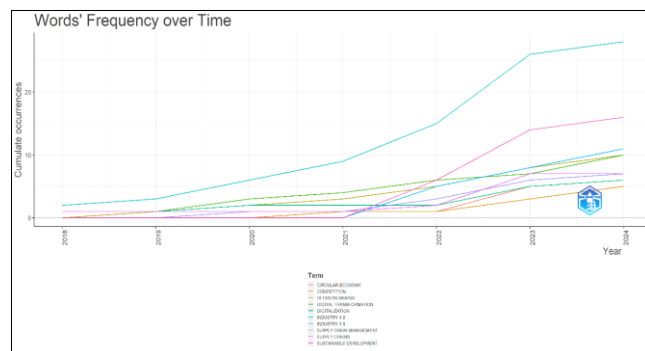


Fig 4: Word Frequency over Time

The growth rates of these keywords exhibit significant trends. For instance, the word "Industry 4.0" had a substantial increase from 2 instances in 2018 to 28 in 2024, suggesting a growing interest in automation and advanced technologies. Likewise, the concepts of "sustainable development" and "Industry 5.0" saw substantial expansion. The frequency of references to "sustainable development" rose from zero in 2018 to sixteen in 2024, while mentions of "Industry 5.0" climbed from zero to eleven over the same period. This represents a shift towards integrating sustainability and human-centred approaches into industrial development. Furthermore, phrases like "digital transformation," "supply chain management," and "circular economy" saw significant growth, highlighting the industry's focus on improving efficiency, flexibility, and ecological impact.

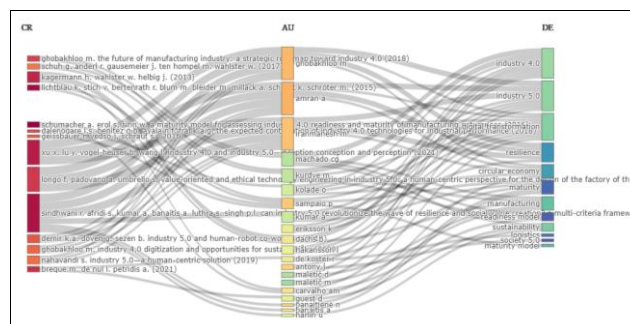


Fig 4: Three-Field Plot

Furthermore, a three-field plot was used to graphically depict the connections between keywords, authors, and sources, providing a comprehensive view of research trends and collaborations in the field. The study uncovered a complex web of interconnected subjects, showcasing the multidisciplinary nature of current research efforts in the field of food processing transitions. This research on keyword mapping and growth rate offers a thorough depiction of the sector's progress from Industry 1.0 to Industry 5.0, emphasizing the continuous dynamic and innovative advancements.

3.4 Mapping the World to Form a Social Structure

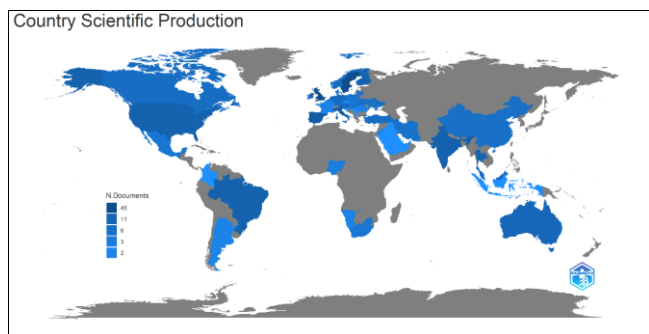


Fig 5: Country Scientific production

3.4.1 Geographical Distribution and Cooperation

The nations shown in blue on the map are actively involved in food processing collaboration, with strong connections mostly taking place between North America, Europe, and Asia. The USA, Germany, and China play pivotal roles as essential hubs for this collaboration.

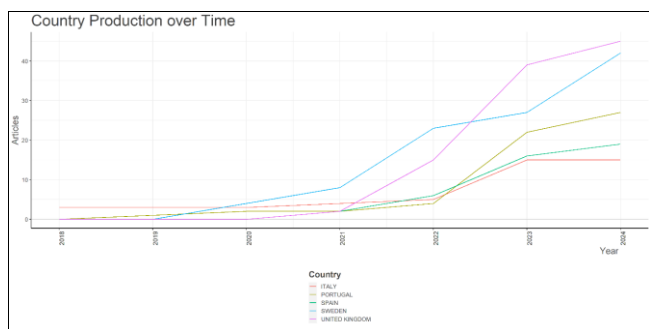


Fig 6: Country production over time

3.4.2 Production Data

The United States, China, and India are the leading countries in terms of food processing production. These nations have seen significant annual growth rates of 4%, 5%, and 6% respectively. These countries are rapidly adopting the principles of Industry 5.0, with a particular focus on automation, artificial intelligence, and sustainability.

3.4.3 Stages of Industrial Transition

The United States, Germany, and China are at the forefront of utilising state-of-the-art technology to improve production and the quality of products. Collaborative efforts focus on the exchange of technology and joint research, particularly among North America, Europe, and Asia.

3.4.4 Geographical Analysis

The United States is the primary investor in artificial intelligence (AI) and automation in North America. Meanwhile, Canada prioritizes cooperation in areas such as sustainability and food safety. Germany is a key player in Europe, leading the way in promoting Industry 5.0 via the use of cyber-physical systems. France and Italy are now focusing their efforts on the advancement of smart manufacturing. China and India, located in Asia, are seeing significant expansion in their food processing sectors as they integrate IoT and AI technologies.

4. The Thematic Study from Industry 5.0 Transition

A thorough analysis of thematic research about Industry 5.0 in food processing is crucial for understanding the evolving dynamics of this industry, particularly as it shifts towards sustainability and human-centred approaches. Descriptive analysis is insufficient as it fails to integrate the intricacies and interrelationships of developing themes, which are crucial for making well-informed decisions (Alhojailan *et al.*, 2012) ^[1].

4.1 Critical Examination of Thematic Studies

Current Developments: A thematic analysis reveals significant growth in Industry 5.0 research, with a focus on key topics such as sustainability and human-centric approaches (Rajumesh, 2023) ^[37].

Inter-disciplinary Discussion: Employing thematic analysis to examine the perspectives of professionals on processed foods improves communication and agreement among different parties involved, so successfully tackling the difficulties related to defining and categorizing processed foods (Sadler *et al.*, 2022) ^[40].

4.2 Thematic Mapping

Descriptive analysis provides a fixed representation of the present condition; yet, it lacks the necessary strategic anticipation needed to negotiate the intricacies of Industry 5.0 in the food processing industry (Hassoun *et al.*, 2023) ^[16]. Industry 5.0 is the most recent era of industrial development, defined by the incorporation of modern technology such as artificial intelligence, the Internet of Things, and robotics into manufacturing processes (Guruswamy *et al.*, 2022) ^[15]. Thematic mapping is an effective method for understanding the important topics and trends in Industry 5.0, categorizing them according to relevance and development state (Ibrahim, 2012) ^[25]. Thematic categories include niche, motor, emerging or declining, and elemental themes.

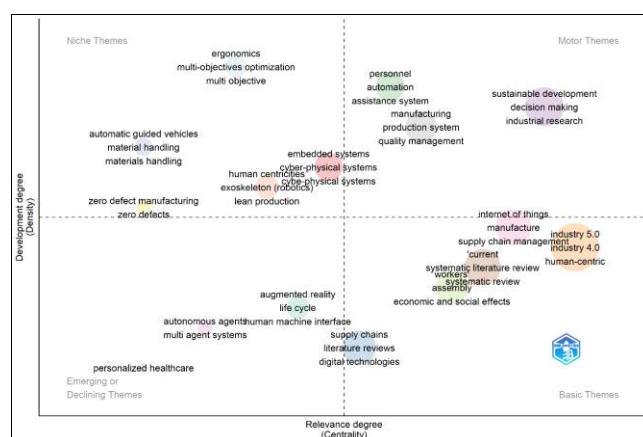


Fig 7: Thematic strategic map

A strategic thematic map is a graphical representation used to visually depict various themes and concepts, assessed based on two criteria: Development Degree (Density) and Relevance Degree (Centrality). The map is divided into four quadrants, each with its thematic categories, with the explicit purpose of promoting originality (Sadler *et al.*, 2022) ^[40].

- **Upper Right Quadrant (Themes of Motor Motion):**
The themes in this quadrant are highly relevant and

thoroughly investigated. These themes are the primary factor that propels the field forward, playing a vital role in its advancement and having significant industrial and research implications (Alvin, 2016) ^[3]. These factors are considered to be the forces that propel the field forward, highlighting their significant influence on significant advancements. Within this category, the diagram illustrates the concepts of sustainable development, quality management, and decision-making. A significant level of both density and centrality defines these subjects as essential to the present research environment. Significantly, the inclusion of "Industry 5.0" and "Industry 4.0" in this quadrant indicates their strong impact on shaping the course of industrial research, sustainability, and human-centred approaches.

- **Upper Left Quadrant (Niche Themes):** They include themes that are significantly elaborated upon but have a lower level of importance or utility. These themes involve specific fields of study but have restricted general relevance. Their significance is comparable to luxurious features found in a car - important to specific individuals but not essential for everyone (Kuch, 1982) ^[21]. Their focus may be on more specialised topics or domains that are not widely embraced within the industry or field. For example, the disciplines of ergonomics, multi-objective optimization, and zero-defect manufacturing are pertinent in specific contexts but may not be universally applicable in all domains. The aforementioned regions are categorized as highly sophisticated and explicitly tailored for exclusive use.
- **Lower Right Quadrant (Themes of Fundamental Nature):** The themes identified in this quadrant are highly relevant but have not yet been properly expounded upon. The corner pertains to fundamental concepts that are the subject of extensive discussion but need a more detailed explanation. The aforementioned themes can be compared to the wheels of a car - indispensable yet still being improved (Alvin, 2016) ^[3]. The aforementioned are essential principles that form the foundation for present research or industrial processes but would benefit from further study or enhancement. To illustrate, the core principles of Industry 4.0, Internet of Things (IoT), supply chain management, and human-centric systems demonstrate that although they are essential for future industrial advancement, they are still in the process of development. Understanding the current and future directions of the industry requires careful examination of these phenomena, which in turn require additional research or technological progress.
- **Emerging or declining themes in the lower left quadrant:** The themes within this quadrant are distinguished by their lower level of significance and insufficient further advancement. They refer to either new areas of study or the obsolescence of current ideas. These can be compared to spare parts - not immediately relevant, but potentially valuable in the future or about to become outdated (Kuch, 1982) ^[21]. They could be either in the early stages of development (emerging) or undergoing a loss of importance and deterioration (Sinha & Matharu, 2019) ^[44]. Relevant examples in the

diagram include "personalised healthcare", "autonomous agents", and "multi-agent systems", suggesting that these topics may either become more important in the future or lose their prominence depending on industry trends. These topics are current subjects of investigation and may either increase in significance or decrease in relevance as they become less feasible in the future.

4.2.1 Constituent Elements of the Thematic Map

- **Significance Degree (X-axis):** This measure serves to indicate the fundamental significance or degree of interconnection of a subject within a specific domain. Themes prominently positioned on the right side hold immense importance, while those positioned on the left side are less central or maybe specialized.
- **Development Degree (Y-axis):** This measures the level of density or severity of the development of a theme. Increased elevation of the theme on the Y-axis is indicative of a higher degree of development or maturity. Themes situated at lower positions on the axis lack both comprehensive development and complete emergence.

Therefore, the thematic map graphically depicts the development of particular topics, their influence on industries, and their capacity to stimulate future advancements in areas such as Industry 5.0, human-centred systems, and supply chain management (He *et al.*, 2011) ^[26].

4.3 Examining Industry 4.0 using Cluster Network Analysis

The network of Industry 4.0 reveals a complex web of interconnected themes and concepts. At the heart of this network, the concept of "Industry 4.0" takes centre stage, emphasizing its pivotal role in the technological and industrial discourse. Centred on this core concept, several important themes emerge, all intertwined through various connections.

Emphasizing the importance of incorporating advanced technologies into industrial processes, phrases such as "technology management," "digital transformation," and "cyber-physical systems" highlight the significance of technological integration and management. These themes emphasize the significance of efficiently overseeing digital tools and platforms to guarantee seamless operations and enhanced productivity.

Supply Chain and Logistics: It is clear that there is a strong emphasis on improving supply chain processes through digitalization, as seen by the significance placed on "supply chain management (SCM)" and "smart logistics". Efficiently managing logistics and supply chains is essential for maintaining a competitive edge in the Industry 4.0 era. The importance of considering human elements in the process of technological transformation is highlighted by the concepts of human factors and ergonomics (HFE) and green skills. Developing new skills and emphasizing intuitive design are essential for fostering a productive and sustainable workforce.

The conversation surrounding the themes of "business model," "economic growth," and "entrepreneurship"

highlights the broader economic importance of Industry 4.0. These aspects highlight the influence of digital transformation on shaping new business models and entrepreneurial ventures, leading to economic growth and promoting innovation.

The presence of phrases such as "sustainable development goals" and "circular economy" indicates a growing emphasis on sustainability in Industry 4.0. Understanding the significance of sustainable practices and circular economic principles is crucial to minimize environmental impact and guarantee long-term viability.

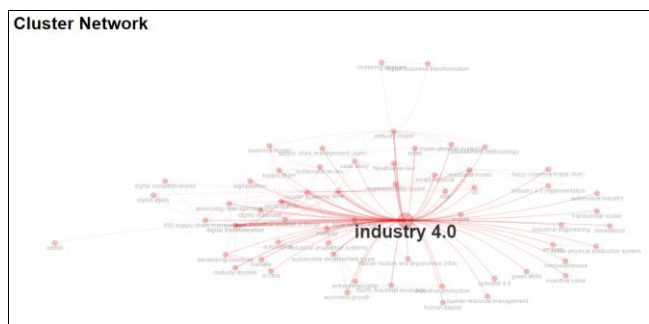


Fig 8: Industry 4.0 cluster network

4.4 Examining Industry 5.0 using Cluster Network Analysis

The cluster network for Industry 5.0 presents a distinct and interconnected array of themes in comparison to Industry 4.0. Here, the central node "Industry 5.0" forms the basis for a network of emerging concepts that demonstrate the evolution of industrial paradigms. Highlighting the transition to a people-centred approach in Industry 5.0 are concepts such as "human-centric design," "human-robot collaboration," and "inclusive workforce." This development highlights the importance of developing technologies and processes that prioritize the welfare of individuals and encourage collaboration with advanced robotics. Highlighting the significance of customized products and services, the idea of "advanced personalization" signifies a move towards highly tailored offerings. This trend is fuelled by the rapid progress in technology, which allows for precise customization based on individual preferences and needs.

Sustainable Practices and Green Industry: Similar to the advancements of Industry 4.0, Industry 5.0 also emphasizes the importance of sustainability, with a particular emphasis on concepts like "green industry" and "green logistics." However, the primary focus is on integrating state-of-the-art technologies to improve efficiency and encourage environmental responsibility. The inclusion of "generative AI impact" and "future of engineering" underscores the importance of cutting-edge technologies in shaping Industry 5.0. These themes highlight the potential of generative AI and other advanced technologies to stimulate creativity and transform engineering practices.

Employment and Competence Development: The network also covers areas such as employment and competence development, emphasizing the ongoing need to ensure that the workforce is equipped to meet the ever-changing technological demands. Ensuring that employees

have the essential skills for the successful implementation of Industry 5.0 initiatives is crucial.

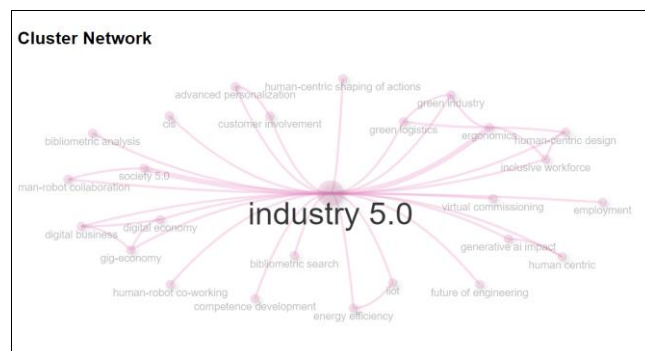


Fig 9: Industry 5.0 Cluster Analysis

The transition from Industry 4.0 to Industry 5.0 signifies a shift from a primarily technology-driven industrial revolution to a paradigm that places greater emphasis on human-centric values and environmental awareness. While Industry 4.0 focuses on the integration of advanced technologies and supply chain optimization, Industry 5.0 prioritizes human collaboration, advanced personalization techniques, and sustainable practices. This shift demonstrates a holistic approach to industrial transformation, where technological advancements are harmonised with human and environmental considerations.

5. Systematic Literature Review

Merely conducting descriptive and thematic studies is insufficient for acquiring a comprehensive understanding of Industry 5.0 in the food processing domain, due to the complex and diverse nature of this sector. A systematic literature review (SLR) is an essential process for synthesizing diverse viewpoints and identifying gaps in existing research. The level of complexity in Industry 5.0 is very high and it cannot be easily comprehended. Therefore, a combination of techniques such as descriptive analysis, thematic and SLR are used to better understand Industry 5.0 (Madhavan *et al.*, 2022) [27].

Industry 5.0 is a paradigm that integrates advanced technology with design principles focused on human needs. It places a strong emphasis on sustainability and resilience within the industrial sector.

The objective of this study is to fill the existing gaps in the current literature by conducting a systematic review that investigates the consequences and challenges associated with the adoption of Industry 5.0 (Narkhede *et al.*, 2023). A Comprehensive Literature Review (SLR) provides a comprehensive framework for evaluating the current state of research, identifying potential opportunities, and highlighting challenges in the food processing industry.

The utilization of this methodology allows for a cautious and careful assessment of various research methodologies and outcomes, thereby ensuring a thorough examination of the correlation between technology and sustainability in the realm of food processing (Antony *et al.*, 2024; Chawla *et al.*, 2024) [4, 9]. Descriptive and thematic analysis, while valuable, are insufficient for comprehensively addressing the complex dynamics of Industry 5.0. The aforementioned statement emphasizes the importance of conducting

systematic reviews to guide future research and inform professional practice.

5.1 Literature Review of Transformation from Industry 1.0 to Industry 4.0

The transition in food during the Industrial Revolution was transferring from agriculture, where food was grown to industries where the food was processed and manufactured (Mathur *et al.*, 2022) ^[28]. The term industrial revolution was coined by Arnold Toynbee wherein it was described these industrial revolutions are not based on the timeline but instead were characterised by economic transformation (Ashton, 1997; Mathur *et al.*, 2022) ^[5, 28].

The growth of the food industry from the beginning to the current day may be traced to many industrial revolutions. The food industry has progressed from Food Industry 1.0 to Food Industry 4.0, with each phase including technical advancements and enhancements in quality control. The industry initially focused on traditional methods (Food Industry 1.0), then progressively transitioned to mechanization and mass production (Food Industry 2.0), and later embraced automation and digitalization (Food Industry 3.0) (Hassoun, 2024) ^[18]. Food Industry 4.0 refers to the current era of the food industry that utilizes sophisticated digital technologies, including the Internet of Things, artificial intelligence, and big data, to enhance food quality, safety, and sustainability throughout the whole supply chain (Aït-Kaddour *et al.*, 2024; Wójcicki *et al.*, 2024) ^[6, 50]. This transformation enables improved efficiency, productivity, and environmental sustainability, thereby establishing the groundwork for future progress towards a complete and multidisciplinary approach in Food Industry 5.0 (Hassoun, 2024) ^[18].

The main differentiations between food industry 1.0 and 4.0 are based on their technological advancements and approaches to improving quality, sustainability, and efficiency. The term "Food Industry 1.0" denotes a historical era characterised by a significant reliance on manual labour for food production. On the other hand, Food Industry 4.0 integrates digitisation, automation, and data-driven decision-making to enhance production and safety (Aït-Kaddour *et al.*, 2024; Ozkan *et al.*, 2024) ^[6, 31]. Industry 4.0 technologies, including the Internet of Things, artificial intelligence, and big data, are revolutionising food production by enhancing processes, ensuring quality control, and promoting sustainability throughout the supply chain (Wójcicki *et al.*, 2024) ^[50]. The concepts of Quality 4.0 and Food Quality 4.0 have emerged to use Industry 4.0 technologies for the production of environmentally sustainable and nutritious food products. These principles strive to meet consumer expectations for superior quality and long-term environmental responsibility. The move from Food Industry 1.0 to 4.0 involves shifting towards a more efficient and ecologically conscious food production environment that prioritises the development of high-quality goods (Aït-Kaddour *et al.*, 2024; Wójcicki *et al.*, 2024) ^[6, 50].

5.2 Review of Transformation to Industry 4.0 and its Status

Industry 4.0, also referred to as I4.0, is being more and more incorporated into the agri-food supply chain to tackle

obstacles and improve sustainability. The literature review focuses on the application of I4.0 technologies in agriculture, known as Agriculture 4.0. It highlights the various advantages, including enhanced food production to meet rising demands, cost savings, improved food safety, and optimized resource management (Derakhti *et al.*, 2023; Yap, 2024) ^[10, 51]. Although the agricultural sector has the potential to be transformed by I4.0, it still faces various challenges. These obstacles encompass technical, operational, financial, social, and infrastructure-related issues. Notable challenges that have been identified include technological architecture, security and privacy, big data management, and IoT infrastructure. However, there is a significant gap in addressing sustainability issues, specifically waste management. The review highlights the significance of utilizing I4.0 technologies to address these challenges and improve the efficiency of managing the agri-food supply chain. It offers a roadmap for academics and practitioners in this field (Derakhti *et al.*, 2023) ^[10].

The agricultural and food industries are undergoing a significant transformation due to Industry 4.0. This revolution is accompanied by a multitude of technological advancements, including smart sensors, artificial intelligence, and Big Data. These groundbreaking advancements are transforming the way we ensure food safety. The integration of Industry 4.0 technologies in agriculture, also known as Agriculture 4.0, is strengthening food safety by employing data-driven decision-making, effective resource management, and improved agricultural practices (Yap, 2024) ^[51]. Quality 4.0 and Food Quality 4.0 have emerged as significant concepts in the Food Industry 4.0. They highlight the significance of creating environmentally friendly and healthier products through the optimization of industrial transformation processes in the supply chain (Aït-Kaddour *et al.*, 2024) ^[6]. By harnessing advanced Industry 4.0 technologies such as smart sensors and blockchain strategies, the food industry can effectively address consumer expectations for top-notch quality and environmental sustainability. As a result, there can be a noticeable increase in efficiency and effectiveness in food safety operations within supply chain management (Almelhem *et al.*, 2022) ^[2]. The transition to Industry 4.0 leads to enhanced requirement for upgraded skill set and knowledge base to achieve increased productivity (Rojko *et al.*, 2020) ^[39].

5.3 Evolutionary Change in Transformation from Industry 4.0 to 5.0

The shift from Food Industry 4.0 to Food Industry 5.0 signifies a significant transformation in the approach of the food industry, as highlighted in the research papers. The primary emphasis of Food Industry 4.0 is on profit-oriented tactics that use digitalization and automation to enhance productivity and efficiency. Food Industry 5.0 is a comprehensive and interdisciplinary strategy to enhance food sustainability, resilience, and cooperation between people and robots in the food and agricultural industry. This transition is a move towards a comprehensive and long-lasting food production system, integrating advanced technology and various strategies to address social concerns and enhance a more resilient and efficient food business (Hassoun, 2024) ^[18].

The use of cutting-edge technology such as artificial intelligence (AI), robotics, and the Internet of Things (IoT) has significantly revolutionized food production in Industry 4.0, resulting in substantial alterations in methods and operations (Rampalli *et al.*, 2024; Wójcicki *et al.*, 2024) ^[38, 50]. Industrial robots have been used in the food processing industry to improve output and ensure food safety and security via effective and hygienic handling of products (Lalita *et al.*, 2023) ^[24]. Autonomous agriculture enabled by AI and robots enhances agricultural conditions in real time, leading to less resource wastage, increased yields, and greater sustainability. Additionally, it addresses challenges like as providing sustenance to an increasing global population, controlling agricultural diseases, and mitigating the impact of extreme weather events (Rampalli *et al.*, 2024) ^[38]. The use of automation in agriculture offers several advantages, such as enhanced administration, decreased expenses, and the attainment of environmental sustainability objectives. Nevertheless, it also gives rise to concerns like unemployment and restricted availability of technology, which need resolution (Pasteur & Emilie, 2024; Rampalli *et al.*, 2024) ^[32, 38]. "Agriculture 4.0, which entails incorporating Industry 4.0 technology into the agricultural sector, has the potential to generate substantial transformations. By using data-driven decision-making and efficiency gains, this technology has the potential to increase productivity, reduce the need for a large staff, improve resource management, and promote sustainable food production (Yap, 2024) ^[51]."

5.4 Transformation to Industry 5.0 and its Role

Industry 5.0, which involves the integration of advanced technologies like IoT, AI, digital twins, and autonomous systems, significantly impacts food production operations. It transforms agricultural operations, enhances crop yields, promotes sustainability, and enables precise decision-making (A. Sharma *et al.*, 2024) ^[42]. Industry 5.0 concepts emphasize the collaboration between people and technology, leading to increased productivity and reduced environmental impact via the use of data-driven precision farming practices (Demircioglu *et al.*, 2024). In addition, the use of deep learning algorithms in business 5.0 enhances energy efficiency, optimizes production processes, and enhances product quality, showcasing the transformative potential of machine learning (ML) and deep learning (DL) technologies in the agricultural business (Goswami *et al.*, 2024) ^[14]. Agricultural applications of robot managers are being researched and implemented as a component of Industry 5.0 initiatives. The objective is to optimize profitability, boost economic indicators, and reduce production costs, eventually resulting in financial benefits for agricultural producers (Baimukhamedova *et al.*, 2023) ^[7].

6. Discussion

Industry 5.0, which involves the integration of advanced technologies like IoT, AI, digital twins, and autonomous systems, has a significant impact on food production operations. It revolutionizes agricultural operations, resulting in enhanced crop yields, promoting sustainability, and enabling precise decision-making which can open new domains for Agri-researchers and industry participants (A.

Sharma *et al.*, 2024; Demircioglu *et al.*, 2024) ^[42]. Industry 5.0 concepts are being used in agriculture to foster collaboration between people and robots. The objective of this partnership is to improve productivity and reduce the negative effects on the environment by using data-driven precision farming methods (Demircioglu *et al.*, 2024). Moreover, the implementation of robotic supervisors in the agricultural sector, a pivotal component of Industry 5.0, enables the incorporation of extensive digital technologies such as big data, artificial intelligence, blockchain, and wireless communication. This integration eventually improves manufacturing profitability and economic indicators, while also reducing expenses for both the government and food industry (Baimukhamedova *et al.*, 2023) ^[7]. To sum it up, Industry 5.0 has a beneficial influence on the processes involved in food production, resulting in improved flexibility, effectiveness, productivity, and cost-effectiveness in the agri-food sector (Kankekar *et al.*, 2023) ^[19].

Industry 5.0 incorporates a range of cutting-edge technologies to improve industrial operations and efficiency. The technologies included in this list are cobots, cloud computing, virtual reality, big data, artificial intelligence (AI) (Kumari *et al.*, 2024) ^[23], complex systems integration (CSI), cyber-physical systems, and the Internet of Things (IoT) (*Emerging Synergies: Industry 5.0 Integration of Complex Systems*, 2024), Machine learning (ML) and deep learning (DL) algorithms, such as artificial neural networks (ANN), recurrent neural networks (RNN), generative adversarial networks (GAN), and boosted regression decision trees (BRDT), are important in Industry 5.0. They contribute to improving energy efficiency, optimizing production processes, and enhancing product quality (Goswami *et al.*, 2024; Sundaram *et al.*, 2024) ^[14, 45]. In Industry 5.0, the integration of IoT devices and sensor networks is a groundbreaking development. It allows for connection, data-driven decision-making, and predictive maintenance, leading to enhanced efficiency and sustainability in industrial processes which can be utilised by practitioners, researchers and regulators in framing new policies related to Industry 5.0 by the government (Singh *et al.*, 2024) ^[38].

7. Conclusion

The paper has discussed three different approaches to literature review, i.e. descriptive analysis, thematic mapping and systematic literature review. Further, the level of complexity in Industry 5.0 is very high, and it cannot be easily comprehended. Therefore, a combination of techniques such as descriptive analysis, thematic and SLR are used to better understand Industry 5.0 (Madhavan *et al.*, 2022) ^[27]. Descriptive analysis provides a fixed representation of the present condition of industrial revolutions, whereas thematic mapping helps to better understand the evolving themes and trends. Lastly, a systematic literature review helps to gain a comprehensive understanding of both the current scenario and future scenarios. Industry 5.0 is vast and complex. Therefore to make it less complex, the industry 5.0 is fragmented into three parts so that it can be easily understood and explained. So based on the above research, academicians, industry participants and legislative people can frame policies and

guidelines for Industry 5.0 and also study the evolving themes and trends related to it for future prospects.

8. Inferences

8.1 Theoretical Inference

The theoretical research discusses the specific technological and methodical developments that occur from Industry 1.0 to Industry 5.0 in the food processing sector. The advent of Industry 1.0 initiated conventional nutritional research, which then evolved into automation during Industry 2.0 and further expanded into digitalisation during Industry 3.0. Industry 4.0 has harnessed the power of AI and the IoT, leading to significant improvements in quality control, productivity, and environmental sustainability. Industry 5.0 focuses on putting humans at the centre, using advanced technologies to support a strong and environmentally friendly food production system. The theme categorization within Industry 5.0, including specialized, motor, emerging or declining, and elemental subjects, offers a comprehensive understanding of current trends and future research opportunities.

8.2 Practical Inference

Essentially, the transition to Industry 5.0 in food processing involves the use of cutting-edge technology to improve industrial processes, ensure food safety, and meet consumer demands for sustainability and customisation. The use of AI, robotics, and the IoT in Industry 4.0 has already transformed agricultural practices, leading to substantial enhancements in both productivity and environmental sustainability. Industry 5.0 enhances these capabilities by promoting collaboration between people and robots and using advanced customisation methods. The study highlights the need to use these technologies to create a resilient agricultural system capable of successfully addressing global challenges such as food security and environmental sustainability.

8.3 Limitations and Future Research Scope

There were very few papers matching exactly with the domain of Industry 1.0 to Industry 5.0 in food processing industry which resulted into inclusion less number of papers in the review analysis. This analysis offers a thorough examination of the progression from Industry 1.0 to Industry 5.0 in the food processing sector. However, it is important to acknowledge and tackle a few constraints. Maintaining an up-to-date evaluation is challenging due to the fast speed of technical changes. Moreover, the adoption of Industry 5.0 technologies differs greatly across various areas and industries, highlighting the need for additional study to comprehend these discrepancies. Future research should prioritize the development of scalable and adaptive models for integrating Industry 5.0 technologies. Additionally, it should investigate the socio-economic effects of these transitions and delve into the ethical problems surrounding growing automation and human-robot cooperation. To fully unlock the potential of Business 5.0 in the food processing business, it is essential to focus on three specific areas.

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