POLITECNICO MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE
E DELL'INFORMAZIONE

Assessing Worker Well-Being in Italy's Food Industry 5.0: The Impact of Digital Technologies

TESI MAGISTRALE IN FOOD ENGINEERING

Leone, Edoardo, 249156

Advisor:
Rita Maria Di Francesco

Academic year:
2024-2025

Abstract: The transition toward Industry 5.0 has renewed attention on the human-centered dimension of digital transformation, particularly in labor-intensive and highly regulated, multi-stage sectors such as the food industry. This study investigates the relationship between digital exposure and workers' wellbeing within the Italian food industry, focusing on both physical and psychological dimensions. Using survey data collected from 127 industry professionals, the study combines descriptive statistics, Partial Least Squares Structural Equation Modeling (PLS-SEM), multi-group analysis, and qualitative insights. The results indicate a positive and statistically significant relationship between digital exposure and perceived physical wellbeing, suggesting that digital technologies are primarily associated with reduced physical workload and improved ergonomic conditions. By contrast, no statistically significant direct relationship emerges between digital exposure and psychological wellbeing. Acceptance of Industry 5.0 human-centered organizational principles is consistently high across the sample, although it appears weakly related to actual technological exposure, indicating a strong normative orientation toward these models. Multi-group analysis further highlights the context-dependent nature of technological impacts, with differences emerging across exposure levels, organizational size, and operational roles. Overall, the findings suggest that within the Italian food industry, digital technologies are not perceived as a systemic psychological threat, while their physical benefits are more clearly recognized. The study contributes empirical evidence to the emerging Food Industry 5.0 literature and highlights the importance of organizational readiness, training, and people-oriented implementation strategies to translate technological innovation into tangible wellbeing outcomes.

Key-words: Industry 5.0, Food Industry, Human-Centricity, Worker Wellbeing

1. Introduction

1.1 From Industry 4.0 to Industry 5.0

Throughout its history, humanity underwent many technological evolutions. This obviously also applies to industry, which, since its origin with the First Industrial Revolution characterized, for example, by the advent of steam-powered machines, has experienced successive revolutions, culminating in the Fourth Industrial Revolution at the beginning of the twenty-first century.

This fourth industrial revolution was characterized by the integration of advanced information and digital technologies (ICT) such as the Internet of Things (IoT), Industrial IoT (IIoT), robotics, cloud computing, big data analytics, artificial intelligence (AI) and Machine learning (ML) and promises to revolutionize industrial processes. These technologies facilitate the collection, transmission, processing and analysis of data in digital format, offering important benefits in various applications [1]. The main focus of this revolution is to use advanced technologies and automation to enhance process efficiency, leading to higher productivity.

While Industry 4.0 (I4.0) has achieved significant developments, including significance economic benefits and technological innovations, there are also some challenges like the high implementation costs, a shortage of skilled labor, cyber and data security risks, and socio-technical implications [2]. Indeed, in general, the employee's role in the Industry 4.0 era has not changed significantly, but the need for employees able to adapt their working attitude to quick, frequent changes in the whole industry scenario represents a huge problem when it comes to the productive reality and societal level at large [3].

In response to these challenges, Industry 5.0 has arisen as a development of the I4.0 paradigm, moving the focus from productivity alone to a more human-centered, sustainable, and resilient industrial model.

The concept of Industry 5.0 (I5.0) is relatively recent and represents an evolution of the Industry 4.0 system. According to the European Commission [4], it's defined as a human-centered, sustainable, and socially responsible approach to production that goes beyond efficiency and productivity as primary goals. It emphasizes the societal value of manufacturing and aims to ensure the well-being of workers while respecting the planet's production limits. By focusing on technological advancement and research to enable environmentally friendly, adaptable, and human-centered European industry, Industry 5.0 enhances and builds upon the foundations established by I4.0.

Within this framework, two complementary perspectives have contributed to shaping the conceptual foundations of Industry 5.0. The first focuses on human-robot collaboration, where intelligent machines and collaborative robots (called cobots) support human workers by performing repetitive, physically demanding, or high-precision tasks, while humans maintain control over creative, cognitive, and supervisory functions [2].

The second perspective emphasizes sustainability and bioeconomy principles, aiming to balance industrial growth with ecological preservation through circular resource use, waste reduction, and environmentally responsible production practices [2]. Together, these perspectives highlight the transformative potential of I5.0 as a paradigm that integrates technological advancement with social and environmental considerations in line with today's global scenario, where people and companies are increasingly sensitive to sustainability in all its dimensions (triple bottom line).

Industry 5.0 is founded on three pillars that summarize the essence of its key topics [5]:

Sustainability: As previously discussed, organizations increasingly integrate sustainability into their policies and practices assisted and promoted by the growing number of incentives offered by different governments. This allows them to conserve natural resources, minimize energy waste, and protect the environment while maintaining competitive industrial performance.

Human-Centricity: Human-centeric approach recognizes the unique value of people, emphasizing their skills, creativity, and problem-solving abilities. While collaborative machines assist in repetitive or high-precision tasks, human talent remains central to innovation and decision-making.

Resilience: The third pillar, resilience, has gained increasing importance in recent years as market continuously change due to various disruptions and global challenges such as the COVID-19 pandemic, geopolitical conflicts, and rising trade barriers. Resilient industries leverage technology to guarantee continuous operations during crises and adapt rapidly to evolving market conditions, helping to maintain stability, competitiveness, and long-term sustainability.

1.2 Food Industry 5.0

The relevance of Industry 5.0 is particularly evident in the food industry, a sector characterized by high complexity, significant uncertainty and frequent disruptions, and exposed to multiple interconnected challenges, including food safety, environmental sustainability, working conditions, and supply chain stability [1].

In particular, the agri-food sector is strongly affected by market seasonality and by a wide range of uncertainties, especially in agriculture, where production is highly dependent on climatic conditions and other unpredictable factors that can significantly disrupt and slow down the entire supply chain [6]. Moreover, the food industry is characterized by a high degree of heterogeneity among supply chain actors, often resulting in structural disparities that make sustainability not only an environmental issue, but also an economic and social one. This is further reinforced by the considerable environmental impact of intensive farming and livestock activities, which contribute substantially to greenhouse gas emissions and resource depletion [7].

In recent years, the agro-food supply chain has undergone significant transformations driven by technological advancements, globalization, the COVID-19 pandemic, and growing awareness of climate change, which have increased uncertainty and vulnerability across production and distribution networks [8].

At the same time, the food industry remains highly labor-intensive and subject to strict quality and safety regulations, while facing increasing pressure to respond to rapidly evolving consumer preferences, such as the growing demand for plant-based products and greater sensitivity towards sustainability and ethical production practices [9].

Industry 4.0 technologies have already contributed to important improvements in food production and supply chain management by enhancing traceability, supporting data-driven decision-making, and enabling the automation of several processes. For example, they have facilitated the adoption of precision agriculture, smart irrigation systems, and automated food processing technologies, allowing companies to increase productivity, reduce waste, and improve environmental sustainability through digital innovation [10]. However, the strong emphasis on efficiency and large-scale production has often overlooked the human dimension of food systems, raising concerns related to job quality, worker stress and safety, ergonomic risks, and the social acceptance of highly automated environments [11].

In this context, the transition towards a Food 5.0 paradigm represents a strategic opportunity to overcome these limitations by integrating technological innovation with human-centered design principles, sustainability objectives, and resilience strategies [1]. Rather than replacing Food 4.0, Food 5.0 can be understood as its natural evolution, reinforcing digital transformation while restoring the central role of human workers within food production systems. By promoting closer and more balanced collaboration between humans and intelligent machines, Food 5.0 aims not only to enhance operational efficiency, but also to improve working conditions, reduce physical and cognitive strain, support worker well-being, and strengthen the resilience of agro-food supply chains in the face of future disruptions.

2. Background

2.1 Worker Alienation and Human-Centered design

The rapid diffusion of Industry 4.0 technologies has raised growing concerns regarding worker alienation and psychosocial risks in highly automated and digitalized work environments. Some studies, such as [12] and [13] have shown that increased automation, algorithmic control, and data-driven monitoring can reduce workers' perceived autonomy, intensify cognitive workload, and contribute to feelings of stress, insecurity, and loss of control over work processes. From a socio-technical perspective, these negative outcomes are not primarily driven by technology itself, but by the way digital systems are designed, implemented, and governed, particularly in contexts characterized by limited worker involvement and insufficient organizational support [13].

At a more granular level, recent empirical evidence further suggests that the effects of AI on workers' experiences depend on how technology interacts with core task characteristics. When AI systems substitute rather than support key aspects of work, such as autonomy, task identity, and task significance, workers are more likely to experience increased alienation and reduced engagement [14].

Such concerns have highlighted the limitations of technology-centered industrial paradigms and have contributed to the emergence of Industry 5.0, which explicitly seeks to address these challenges by re-centering industrial systems around human needs, wellbeing, and participation.

In the context of Industry 5.0, worker well-being and human-centered approaches are key elements that complement technological innovation with a focus on the physical, cognitive, and emotional needs of employees. One important aspect of this vision is **well-being monitoring**, which typically involves the use of lightweight wearable sensors and other technologies to assess posture, movement, physiological parameters such as heart rate, and indicators of stress. These tools are employed not only to prevent injuries and reduce fatigue, but also to improve overall safety and comfort in the workplace, as demonstrated by recent systematic reviews of ergonomic monitoring technologies in industrial settings [15].

A second main concept is the **"Human-In-The-Loop" (HITL) model**, in which human operators maintain control and supervision responsibilities, while automated systems and robots adapt in real time to the needs, conditions, and work rhythms of human workers. This approach recognizes that human expertise and decision-making are essential components of effective human-machine collaboration, and it forms a cornerstone of human-centric manufacturing strategies promoted in Industry 5.0 research [16].

Closely related to this is the **active involvement of workers** in the design and implementation of new technologies. In human-centered development processes, employees are consulted through feedback sessions, pilot tests, and participatory design activities before technologies are introduced or modified, ensuring that systems are not only efficient but also acceptable and beneficial for those who use them [17].

The concept of **human-centered design** emphasizes placing people at the core of industrial systems, searching a balance between technological efficiency, worker well-being, workplace safety, and job quality. This holistic perspective goes beyond reducing physical strain to consider mental workload, cognitive ergonomics, and the overall work experience, aligning with the human-centric paradigm of Industry 5.0 that aims to create sustainable, inclusive, and resilient industrial environments [17].

2.2 Government policies and incentives for Industry 5.0

In Italy, the concept of Industry 5.0 has become an integral part of the national industrial agenda [18], particularly within the broader framework of digital and energy transition. Although still emerging, several manufacturing companies are gradually implementing measures such as incentive programs: according to a survey of Italian manufacturing firms, about one in five firms has already utilized incentives linked to the 5.0 transition, while nearly half plan to implement them in the coming years to support technological innovation, sustainability, and digitalization [19].

The Italian government has introduced the "Transizione 5.0 Plan", part of Mission 7 of the National Recovery and Resilience Plan (PNRR) and connected to REPowerEU resources. This plan allocates approximately €12.7 billion for 2024-2025 to encourage productive investments that enhance energy efficiency, digitalization, and technological innovation [20].

Key mechanisms include tax credits for investments in both tangible and intangible assets relevant to the digital and green transition, with rates up to 45% of eligible costs if the investment achieves significant energy savings. Eligibility typically requires a minimum 3% reduction in total plant energy consumption or a 5% reduction in the relevant production process [21]. The measures aim not only to stimulate technology adoption but also to enhance the international competitiveness of Italian firms by fostering innovation and sustainability. Moreover, discussions are ongoing to extend the incentives until April 2026, providing additional time for investment planning and implementation [22].

There are no incentives exclusively targeting the food industry, the "Transizione 5.0" measures are applicable to all companies making investments aligned with sustainability and energy efficiency requirements, including operators in the food sector. National platforms also report funding opportunities for food and beverage companies under digital and green transition programs, which can be combined with Industry 5.0 incentives for sector-specific innovation projects [23].

When comparing Italy's experience with Industry 5.0 to the broader European context, both share common strategic goals, focusing on a human-centric, sustainable, and resilient industry. However, there are differences in implementation.

At the European level, the Commission emphasizes a strategic vision supported by initiatives such as the Industry 5.0 Community of Practice, which brings together stakeholders to share best practices and foster collaboration across member states [24]. In Italy, the approach is more operational, connecting digital transformation with energy efficiency through targeted incentive programs like the "Transizione 5.0 Plan", which provides funding for companies adopting advanced technologies with measurable energy savings [20]. Compared with Europe's broad policy framework, Italy's measures rely directly on fiscal instruments, such as tax credits, and have defined timelines (2024-2025), although uptake has been partial, with only a fraction of funds effectively used by firms [19].

3. Literature review

3.1 State of the Art on Food Industry 5.0

The scientific literature available in online databases concerning the concept of Industry 5.0 is currently limited, probably because, as already anticipated in the previous paragraph, the concept has only emerged in recent years and is still under development. If two additional research constraints related to the food industry and sustainability issues are considered, since these represent the specific research interests of this study, the field of investigation becomes even more restricted. Nevertheless, some contributions are relevant and deserve to be cited to gain a better understanding of the topics addressed and therefore arrive at the focus of this project.

Several recent studies, such as [2], [25] and [26], have examined the application of Industry 5.0 technologies in the food and agri-food sectors, particularly in relation to resilience, transparency, and sustainability. Research highlights those digital technologies, including big data, artificial intelligence, digital twins, Internet of Things, and edge computing, can enhance food supply chain resilience and traceability, enabling more transparent and responsive systems capable of mitigating disruptions and improving overall operational efficiency.

Closely related, other articles, [27] and [28], emphasize the management of perishable goods and food waste, showing that Industry 5.0 technologies, such as AI, collaborative robots, blockchain, IoT, and cloud computing, can reduce losses, optimize recovery or recycling strategies, and support the transformation of waste into energy, bioplastics, or fertilizer, thus contributing to both sustainability and supply chain efficiency.

Furthermore, [29] highlights the importance of traceability systems in food supply chains, for example through RFID-based frameworks, which facilitate real-time monitoring, data sharing, and quality control while addressing operational challenges in complex logistics networks.

From a social perspective, [30] investigating societal livelihood and food safety in short food supply chains shows that Industry 5.0 approaches can strengthen consumer confidence, support local economies, and enhance the ethical and sustainable management of food resources.

At the organizational level, [31] shows that human-centric principles and ESG integration positively influence company performance. This work underlines how worker involvement, fair governance, and sustainable practices can enhance capital profitability and long-term enterprise resilience.

Further research confirms that ESG integration and human-centered digitalization can significantly affect company profitability and operational efficiency, showing that innovation, financing, and operational effectiveness increase capital returns, while high costs reduce them, thereby highlighting the benefits of aligning Industry 5.0 and ESG principles [32].

Some recent studies focus on workforce training, upskilling, and human-technology interaction within the Industry 5.0 paradigm. In this context, approaches based on natural language processing, semantic similarity, and personalized learning frameworks have been shown by [33] to improve tacit knowledge extraction, employee engagement, and the adoption of Industry 5.0 technologies, thereby fostering social sustainability and human-centered innovation.

Complementarily, other research highlights the importance of the continuous involvement of strategic knowledge workers across all phases of knowledge creation for a successful transition to Industry 5.0, emphasizing collaboration among operators, decision-makers, and managers to ensure human-centric implementation and organizational learning [34].

The literature also highlights the importance of comprehensive adoption strategies focusing on technology acceptance, change management, and knowledge sustainability. In this regard, according to [35], integrating the ADKAR change management methodology with intangible asset management in a food sector case study significantly improved process efficiency and employee acceptance of new technologies, highlighting the centrality of human-centered transition strategies in Industry 5.0.

In terms of sustainability performance, the literature highlights a clear evolution from Industry 4.0 to Industry 5.0. A systematic review of digital technologies applied to sustainability in the agri-food sector shows that current Industry 4.0 implementations have been predominantly oriented toward environmental sustainability, while social and economic dimensions remain comparatively underexplored, thus motivating the need for a transition toward the Industry 5.0 paradigm [36].

Empirical evidence supports this shift, demonstrating that the adoption of Industry 5.0 oriented digital technologies can effectively enhance sustainability performance across all three dimensions of the triple bottom line. In particular, quantitative studies conducted in different national contexts, such as [37] and [38], confirm that Industry 5.0 contributes positively to economic, environmental, and social sustainability, while also fostering circular economy practices and overall firm performance.

From a practical agri-food perspective, research such as [39] identifies the critical role of AI, IoT, and blockchain in optimizing food quality management and ensuring food security, while studies like [40] show how drones and other precision technologies in Agriculture 5.0 can address sustainability challenges, including pesticide hazards, plant diseases, environmental pollution, and worker safety, thereby enhancing productivity and operational resilience.

Finally, a real-world case study, such as the CANTINA 5.0 project [3] in Italy, demonstrate that employees are generally positive toward collaboration and data monitoring for well-being, indicating that human-centered and digitalized approaches can be successfully integrated in the food industry context.

The reviewed literature highlights a growing academic interest in Industry 5.0 and its application within the food and agri-food sectors, particularly in relation to sustainability, resilience, and technological innovation. Existing researches consistently show that advanced digital technologies can significantly improve efficiency, traceability, and environmental performance across food supply chains, supporting more transparent, resilient, and sustainable production systems.

However, the analysis also reveals a clear imbalance in current research. While environmental and economic dimensions of sustainability are widely addressed, the social dimension, especially workers' well-being, remains comparatively underexplored. Human-centered principles are frequently discussed at a conceptual or strategic level, yet empirical evidence on how digital technologies concretely affect workers' lived experiences in food production contexts is still limited.

However, some recent articles begin to address these issues and provide initial insights into how human-centricity may be operationalized within Industry 5.0-oriented food systems. In particular, case-based as [3] and framework-oriented studies as [35] and [33] show that integrating digital technologies with explicit attention to human capital, organizational change, and skill development can support more inclusive and socially sustainable transitions. These works emphasize the importance of monitoring worker well-being, fostering participation and acceptance of technological change, and investing in personalized training and upskilling strategies as key enablers of human-centered Industry 5.0 implementation in the food sector.

At the same time, analyses focusing on the socio-economic dimension of human centricity highlight that, although the food industry appears structurally sensitive to people-centered transformations, human-centricity is often addressed through aggregated indicators or governance-level measures rather than through direct investigation of workers' perceptions, experiences, and psychosocial outcomes. As a result, existing evidence remains fragmented and does not yet provide a comprehensive understanding of the impact of Industry 5.0 technologies on worker well-being in real operational environments.

3.2 Research Gap

Despite the growing attention devoted to Industry 5.0 and Food 5.0 in institutional narrative and academic literature, research in this field remains fragmented and at an early stage of development. As shown by the synthesis of analysed studies reported in Tables 1-4 (see Section 4.1.6), existing contributions differ substantially in terms of research focus, methodological approaches, and levels of analysis.

While sustainability and resilience have received increasing scholarly attention within the Food Industry 5.0 literature, most studies continue to focus primarily on technological performance, environmental efficiency, or supply chain-level outcomes. Empirical investigations adopt heterogeneous methodological approaches, which limits cumulative synthesis and contributes to a fragmented body of knowledge.

Within this literature, the social dimension of sustainability is present but unevenly developed. As shown in Tables 1-4, social sustainability is mainly addressed through themes such as food waste reduction, supply chain ethics, or consumer-related outcomes, whereas only a very limited number of studies explicitly examine human-centricity, worker wellbeing, or human-centered Industry 5.0 models in food production contexts. As a result, the impact of human-technology interaction on the physical and psychological wellbeing of food industry operators remains insufficiently explored through direct empirical evidence.

Addressing this gap is essential to fully realize the human-centered vision of Industry 5.0, which emphasizes worker wellbeing, participation, and meaningful human-machine collaboration alongside technological efficiency, and to support the development of food systems that are not only efficient and sustainable but also socially inclusive.

From this perspective, this research aims to focus on the following research questions (RQs):

RQ

How does the integration of digital and collaborative technologies within the framework of Food Industry 5.0 affect workers' overall well-being?

RQ1. To what extent do human-machine collaboration and automation reduce or increase work-related stress and employees' sense of alienation in Food Industry 5.0 environments?

RQ2. How do digital technologies (e.g., collaborative robots, artificial intelligence, digital twins) influence workers' perceptions of physical safety, ergonomics, and injury risk within Food Industry 5.0?

RQ3. How are human-centered organizational solutions and principles that support a sustainable balance between technological efficiency and human centrality perceived in Food Industry 5.0 workplaces?

4. Methodology

4.1 Literature review

This study adopts a systematic literature review (SLR) methodology to examine the current state of knowledge on Industry 5.0 within the Food and Beverage and packaging sectors, with a specific focus on sustainability and, in particular, social sustainability. This approach is widely recognized as an effective method for identifying research gaps, synthesizing current findings, and establishing a solid conceptual foundation for emerging research domains.

To ensure methodological rigor, the systematic literature review was conducted through a structured, transparent, and replicable process, in line with established methodological guidelines. The search strategy, screening process, and study selection criteria were defined a priori to ensure consistency with the research objectives and questions, thereby reducing potential bias and enhancing the reliability of the findings.

Figure 1 presents the PRISMA flow diagram, which illustrates the different phases of the article selection process adopted in this study. Specifically, the diagram outlines how records were identified through database searches, subsequently screened and assessed for eligibility, and finally reduced to the set of studies included in the review.

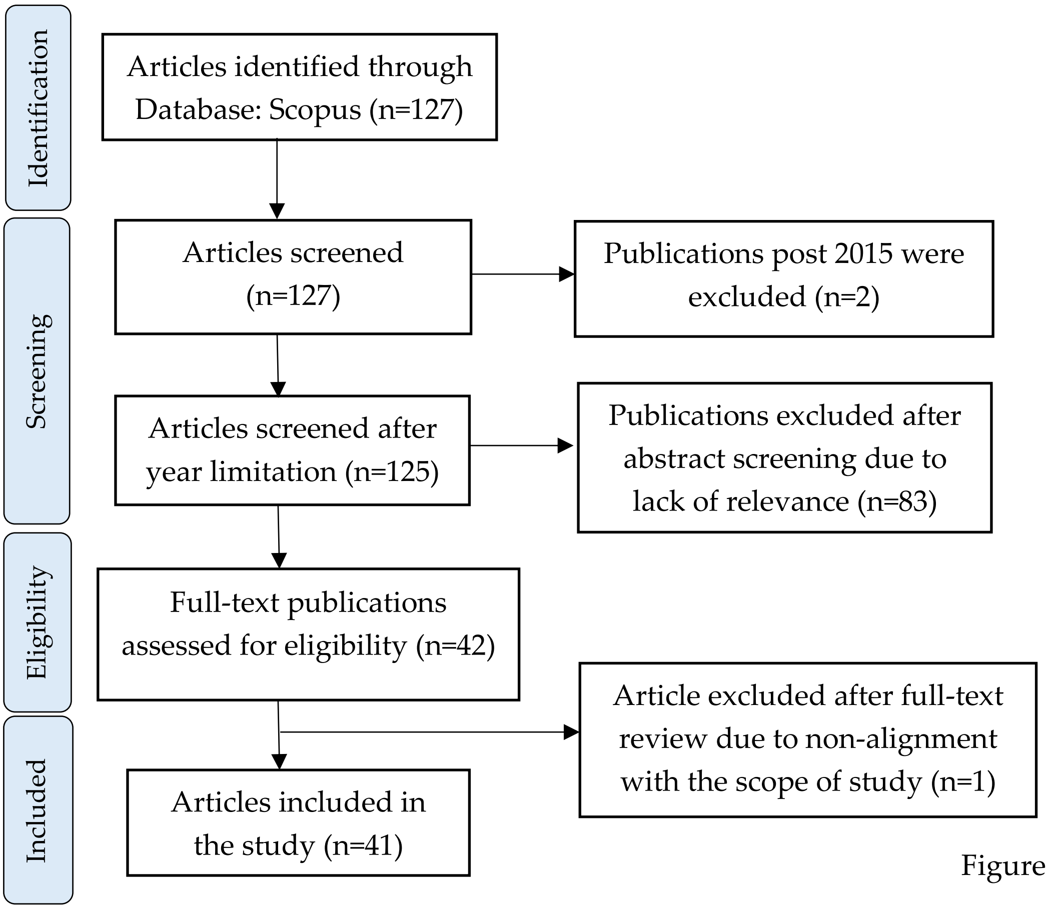


Figure 1: PRISMA DIAGRAM

4.1.1 Database Selection

In order to ensure a rigorous and high-quality literature search, Scopus was chosen as the primary source of scientific publications. Scopus, indexed by Elsevier, is one of the most comprehensive and authoritative databases of peer-reviewed scientific literature. It includes millions of articles, books, and conference proceedings and provides advanced search functionalities that combine keywords, Boolean operators, and disciplinary filters, enabling the systematic identification and retrieval of relevant studies within a given research domain.

4.1.2 Search Strategy and Query Development

A multi-step search strategy was designed to identify studies at the intersection of the three core themes of the research:

1. Industry 5.0 / smart industry
2. Food and Beverage / packaging industries
3. Sustainability, with emphasis on social sustainability and well-being

To achieve this, several exploratory queries were first tested on Scopus to understand the breadth of available literature and to refine the combination of keywords. The final search query incorporated a comprehensive set of keywords and Boolean operators covering the three thematic areas:

- Industry 5.0 concepts (e.g., *"Industry 5.0"*, *"fifth industrial revolution"*, *"advanced manufacturing"*)
- Food and Beverage and packaging sectors (e.g., *"food industry"*, *"beverage industry"*, *"packaging industry"*)
- Sustainability and social sustainability (e.g., *"social sustainability"*, *"worker well-being"*, *"human-centricity"*, *"human–machine collaboration"*)

The final query used in Scopus was:

("Industry 5.0" OR "fifth industrial revolution" OR "Industry5.0" OR "smart industry" OR "advanced manufacturing") AND (sustainab* OR "social sustainability" OR "human centric*" OR "human-centered" OR "human centricity" OR "worker well-being" OR "employee well-being" OR "psychosocial health" OR "human-machine collaboration" OR "human-robot collaboration" OR "worker stress" OR "worker wellness" OR "worker alienation" OR "employee well being" OR "employee satisfaction") AND ("food*" OR "beverage*" OR packaging OR "packaging industry" OR "food industry" OR "beverage industry" OR "agro-industry" OR "agroindustry" OR "agrifood" OR "agri-food industry" OR "food supply chain" OR "food processing" OR "food manufacturing")

In addition to keyword searches, disciplinary filters (LIMIT-TO) were applied to include relevant subject areas such as Engineering, Computer Science, Business, Energy, Agriculture, Social Sciences, Environmental Science, Materials, Economics, Psychology, Decision Sciences, Chemistry, Chemical Engineering, Mathematics, Multidisciplinary, Earth and Planetary Sciences, Arts and Humanities. Categories considered irrelevant to the study such as Nursing and Medicine were excluded to avoid retrieving unrelated literature. In addition, a language filter was applied to include only publications in English.

The search returned 127 results.

4.1.3 Data Export and Cleaning

To prepare the dataset for the screening phase, all retrieved publications were exported from Scopus using the database's export function. The exported CSV file included the following fields, selected for their relevance to the screening and analysis processes: *Authors, Author Full Names, Author IDs, Title, Year, Source Title, Citations, DOI, Link, Abstract, Author Keywords.*

A custom Python script was developed to clean, preprocess, and restructure the exported dataset. The script generated a new table with only the variables relevant for the initial screening and added an additional column aimed at performing a first automated filtering step based on the presence and relevance of specific keywords.

The resulting Excel file contains eight key columns:

TITLE	YEAR	AUTHOR(S)	CITATIONS	DOI	ABSTRACT	KEYWORDS	INCLUDE(YES/NO)

with an additional column alongside for any further comments useful for the subsequent in-depth analysis.

4.1.4 Screening and Eligibility Criteria

The screening process consisted of several criteria:

• **Title, abstract, and keyword screening**

All abstracts were carefully read to assess relevance to Industry 5.0, Food and Beverage/packaging, and sustainability/social sustainability. Articles automatically flagged as non-relevant by the Python script were still manually reviewed to ensure that no potentially relevant studies were excluded.

• **Publication year filter**

Since Industry 5.0 is a relatively new concept, studies published before 2015, when the industry 5.0 paradigm emerged for the first time, were excluded to avoid including outdated or imprecise insights.

After this phase, 42 articles remained.

4.1.5 Full-Text Review and Final Selection

A second Excel file was created to conduct the full-text analysis of the shortlisted articles. Each study was read in depth and categorized according to: **Main research topics**, **Research questions**, **Methodology** (e.g., empirical study, conceptual paper, literature review), **Sustainability focus** (environmental, social, economic), **Industrial context**, **Key findings**, **Research limitations**.

In addition to the primary search in Scopus, Google Scholar was extensively used to complement the literature retrieval. This platform provides a freely accessible database of scholarly articles across disciplines, allowing the retrieval of full-text documents via DOI links when available. Relevant studies identified through Google Scholar were downloaded and included in the dataset for the subsequent full-text analysis.

During the full-text assessment, one additional article was excluded due to lack of relevance, resulting in a final dataset of 41 articles included in the systematic review.

4.1.6 Summary Tables of Literature Review Findings

The tables below summarize all the studies identified in the literature review, classified according to topics, methodology, sectoral context, and sustainability dimensions addressed.

Table 1: Summary of analyzed studies on Food Industry 5.0 (First Part) - continue

Study	Methodology	Topics	Scenario	Sustainability		
				Environmental	Social	Economical
[58]	Case Studies / Design Science	Industry 5.0 framework; Human-centric manufacturing; Reconfigurable Matrix-structured Manufacturing System (RMMS); Order Feature Analysis; Cell formation; Multidimensional reconfiguration	Manufacturing	X	X	X
[47]	Mixed-Methods Empirical	Industry 5.0/Education 5.0; Asset Management; Social Innovation; Design Thinking; Human-centric education	Educational facilities (AgroLab)	X	X	
[45]	Advanced Quantitative / Decision-Support	Agriculture 5.0; Digitalization; Food security; Sustainability (SDGs)	Agriculture Emerging countries	X	X	
[59]	Literature Review	Digital technologies (Blockchain, IoE, Print 4D, Deep Learning, Cloud-Edge Collaboration); Sustainability impacts; transition from Industry 4.0 to Industry 5.0	Packaging	X		
[46]	Mixed-Methods Empirical	Transition to Industry 5.0 for small rural producers (traditional recipes); Local food sustainability (active heritage, coopetition, instinctive sustainability, institutional support)	Small rural producers	X	X	X
[53]	Qualitative Empirical	Industry 5.0 implementation in SMEs; Digitalization while preserving traditional values; Case study of family-owned SMEs in Sri Lanka	Family-owned SMEs, Sri Lanka	X		X
[27]	Literature Review	Food waste challenges; Food waste prevention & reduction; Industry 5.0 technologies (cobots, AI, blockchain, cloud computing, IoT, bioprocessing, DT)	Waste management for food industry	X	X	X
[2]	Literature Review	Big Data/AI; IoT; Edge computing; Cobots; Blockchain; 6G; AR/XR; Smart packaging; Digital twins for Industry 5.0 in food	Food industry (dairy, cereal, tea/coffee, fruit & veg, etc.)	X	X	X
[30]	Literature Review	Short food supply chains; Supply chain resilience; Societal livelihood; Sustainability & human-centric SFSC	Short food supply chain	X	X	X
[29]	Advanced Quantitative / Decision-Support	Traceability barriers in Industry 5.0 food supply chains (RFID systems); Technology Organisation Environment (TOE) framework	Food supply chain (India/emerging markets)	X		

Table 2: Summary of analyzed studies on Food Industry 5.0 (Second Part) - continue

Study	Methodology	Topics	Scenario	Sustainability		
				Environmental	Social	Economical
[31]	Advanced Quantitative / Decision-Support	Human-centricity in Industry 5.0; Socio-economic indicators (gender equality, fair internal market, deeper monetary union, youth participation)	Manufacturing		X	
[49]	Literature Review	Internet of Everything (IoE) and smart sensors; Blockchain; Big Data Analytics and Cloud Computing; 3D Food Printing; Artificial Intelligence (AI)	Agricoltural	X		X
[44]	Literature Review	Artificial Intelligence (AI); Blockchain; Cobots; Precision Farming; Plant-based and alternative proteins; Circular Economy; Sustainability challenges in Food Industry 5.0	NA	X	X	X
[5]	Literature Review	Big Data analytics; Artificial Intelligence (AI) in the food industry; Data collection (IoT sensors); Data mining and Machine Learning; Quality control; Consumer data analysis	NA			X
[1]	Literature Review	Precision farming; AI; Internet of Things (IoT); Robotics; Blockchain; Socio-economic implications of digital agriculture (job creation, skill development)	Agricoltural	X	X	X
[25]	Literature Review	Resilience in food supply chains; Government Policies and COVID-19 impacts; Industry 5.0 technologies (AI, Big Data, IoT, Blockchain, Cobots, Digital Twins);	NA			X
[32]	Advanced Quantitative / Decision-Support	Industry 5.0 (technological & human-centricity); ESG principles and corporate performance analysis; Impact of ESG on Return on Capital / Redditivity of companies	NA			X
[37]	Empirical Quantitative Survey-Based	Industry 4.0/5.0 tech & Circular Economy impact on sustainable performance	Food Manufacturing Pakistan	X	X	X
[9]	Literature Review	Industry 5.0 and Supply Chain 5.0; Human focus; Resilience; Sustainability; Agri-food supply chain indicators	NA	X	X	X
[51]	Mixed-Method Empirical	Logistics 5.0; Foundation Models (FMs); Artificial Intelligence (AI); Green Logistics; Sustainability-Oriented Innovation(SOI).	Logistics (Global; Italian 3PL cases)	X		X

Table 3: Summary of analyzed studies on Food Industry 5.0 (Third Part) - continue

Study	Methodology	Topics	Scenario	Sustainability		
				Environmental	Social	Economical
[28]	Advanced Quantitative / Decision-Support	Ripple effect and supply chain resilience; Food supply chain perishability; Feature extraction for AI; Industry 5.0; Explainable AI (XAI)	Dairy industry (Ukraine, war); Egg supply chain (UK, COVID-19)	X	X	X
[11]	Literature Review	Industry 5.0; AI; Digital Twin; Blockchain; IoE; Nanosensors; Cobots; 4D/5D Printing; Metaverse; 6G	NA	X	X	X
[43]	Empirical Quantitative Survey-Based	Agriculture 5.0; Industry 5.0; Sustainable Development (economic, social, environmental); Environmental Policy; Stakeholder theory	China agri food sector	X	X	X
[56]	Empirical Quantitative Survey-Based	Human-centricity; Industry 5.0; Cognitive assistance systems; Intralogistics (picking & packaging); Usability; User Experience; Technology acceptance	Logistics	X	X	X
[35]	Case Studies / Design Science	Knowledge management; ADKAR Change Management methodology; Industry 5.0; Human-focus; digital transformation.	NA		X	X
[50]	Empirical Quantitative Survey-Based	Global Value Chain; Industry 5.0 Readiness (Human-Centricity, Fairtrade Practices, Lean Management, Sustainability Practices); Business Competitiveness; Sustainable Business Growth.	Thailand Marine food processing SMEs	X	X	X
[3]	Mixed-Methods Empirical	Industry 5.0; human-centricity (workers' well-being monitoring); environmental sustainability; IoT and AI technologies; Food quality assessment	Italian Wine sector	X	X	
[39]	Empirical Quantitative Survey-Based	Human-centricity; Industry 5.0 Drones; Agricolture problems (pesticide hazards, plant diseases, pollution, workers' safety); Sustainability	Nigeria agricoltural	X	X	X
[22]	Advanced Quantitative / Decision-Support	Human-centricity; Industry 5.0 AI/ML applications (MLP, RNN, DL/CNN); Food safety and quality; Smart processing; Sustainability; Big Data	NA	X	X	X
[36]	Literature review	Industry 4.0/5.0 technologies (AI, Big Data, IoT, sensors, blockchain); Human-centricity; Digital transformation of agri-food; Sustainability & Triple Bottom Line	NA	X	X	X

Table 4: Summary of analyzed studies on Food Industry 5.0 (Fourth Part)

Study	Methodology	Topics	Scenario	Sustainability		
				Environmental	Social	Economical
[40]	Literature Review	Human-centered AI; Smart farming & Precision agriculture; Agriculture 5.0; Industry 4.0/5.0 digital technologies; Ethical and social implications	Agricoltural	X	X	
[33]	Case Studies / Design Science	Industry 5.0; Human-centric manufacturing; Workforce training & upskilling;AI-based training systems (NLP, LLM); Quality control & Zero Defect Manufacturing	Food processing		X	X
[38]	Empirical Quantitative Survey-Based	Industry 5.0; Sustainable Performance (STP); Triple Bottom Line; I5.0 technologies (AI, Big Data, IoT, Edge computing, Autonomous robots, AR)	China Agri Food	X	X	X
[52]	Case Studies / Design Science	Industrial Internet of Things(IIoT); Machine Learning/AI; Energy efficiency; Smart manufacturing; Industry 5.0; Data-driven optimization	Manufacturing / industrial energy management	X		X
[57]	Qualitative Empirical	Life-long learning (LLL); micro-credentials; up/reskilling agricultural workforce; Industry 5.0; human-centric digital skills (AI, IoT, data literacy)	Agricoltural		X	X
[34]	Case Studies / Design Science	Organizational Knowledge Creation (Nonaka and Takeuchi model); Industry 5.0; human-centric innovation; university–industry collaboration; co-creation processes	Norway industry (marine seacolture and maritime)		X	X
[54]	Literature Review	Food recommender systems; Human-centric design; Sustainable food consumption; Behavior change theories (TPB, SCT, HBM, Nudge); Semantic & Explainable AI (XAI); Privacy and filter bubble	NA	X	X	
[26]	Literature Review	Food SupplyChain; Food Security & Resilience; Industry 5.0 technologies(AI/Big Data, DT IoE, Cobots, Blockchain)	NA	X	X	X
[10]	Advanced Quantitative / Decision-Support	Logistics 5.0; Green logistics (warehousing, transport, packaging); Decision Support Systems; MCDM; Sustainability	Logistics	X		X
[48]	Literature Review	Traceability and Safety in Agri-Food Supply Chain; Cybersecurity and Scalability Challenges in BIoT networks; Industry 5.0 technologies (AI, Big Data, IoT, Blockchain, Edge computing); Agri-SCM-BIoT	NA		X	X
[55]	Literature Review	Sustainable manufacturing; CPS and Digitalization (Automation, IoT); Human-machine interaction & Ergonomics; Resilience and Socio-technical Systems	Manufacturing	X	X	X

As can be observed, the majority of the contributions focus primarily on technological, economic, and environmental topics, with particular emphasis on digital technologies (e.g., AI, IoT, blockchain, digital twins) and their implications for Industry 5.0 transitions in agri-food and manufacturing contexts. With respect to methodology, the literature appears methodologically heterogeneous. Most contributions consist of literature reviews, while empirical studies remain comparatively limited. Among empirical contributions, most adopt quantitative survey-based approaches, whereas qualitative case studies and mixed-methods designs are relatively scarce. This distribution reflects the early and exploratory stage of Industry 5.0 research within the food sector.

The "scenario" column highlights that most contributions adopt a general or conceptual Industry 5.0 perspective, while only a limited number of studies focus on concrete applications within the food industry, often through isolated case studies. This reinforces the need for empirical research grounded in real food production contexts. Overall, sustainability is widely addressed in the Food Industry 5.0 literature across its three core dimensions: environmental, economic, and social. However, when focusing specifically on the social dimension, most studies predominantly examine issues such as food waste reduction, supply chain ethics, or consumer-related outcomes. Only a very limited subset of contributions (specifically four studies) explicitly focuses on human-centricity, worker wellbeing, or human-centered Industry 5.0 models.

4.2 Quantitative Survey

4.2.1 Questionnaire design and structure

Following the literature review on Food Industry 5.0, a quantitative survey was developed to address the study's research questions. The questionnaire was implemented in Google Forms and consisted of 25 questions/statements plus an optional open-ended field for additional comments.

The survey was structured into six different parts. In the first section, a five multiple-choice questions were used to profile respondents and contextualize the sample: (Q1) industrial segment (Food, Beverage, Packaging), (Q2) department/functional area (e.g., Production, Logistics, Quality Control, etc.), (Q3) years of experience in the food-related sector, (Q4) company size (number of employees), and (Q5) country of employment.

This profiling section was designed to support descriptive analysis and exploratory comparisons (e.g., across departments and company size). More importantly, it allows for a clear characterization of the sample prior to statistical modelling. Given the heterogeneity of respondents in terms of organizational role, company size, and technological context, understanding the sample profile is essential to properly contextualize the results and interpret subsequent PLS-SEM findings.

From Q6 onward, questions were formulated as statements rated on a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). For items Q8 and Q9, the scale ranged from 1 (Never) to 5 (Always). The second section (Q6-Q7) assessed respondents' familiarity with the Industry 5.0 concept and the perceived presence of Industry 5.0-related digital systems and technologies in their work environment. The third section (Q8-Q9) measured digital technologies exposure, capturing the extent of respondents' interaction with digital tools and the level of training received in relation to these technologies. This part (Q6-Q9) is important to contextualize the findings, as it provides an indication of the respondents' level of awareness and organizational exposure to Industry 5.0 and Digital Technologies. Such contextual information supports a more accurate interpretation of subsequent results, particularly those related to attitudes and perceived well-being implications.

The final three sections correspond to the main constructs investigated in the study and directly address the research questions. Specifically, Q10-Q15 were initially designed to capture psychological wellbeing implications. However, during measurement model assessment, item Q10 was excluded and two alternative specifications were tested.; Q16-Q19 assessed perceived physical well-being implications; and Q20-Q25 measured respondents' attitudes toward Industry 5.0 and human-centered models.

Before the final section of the questionnaire (Q20-Q25), a short note was included to briefly introduce and explain key definitions and core concepts related to Industry 5.0 and human-centered organizational practices. This introductory clarification was intended to support respondents' understanding of these topics, which may not be equally familiar to all participants, and so to enable a more reliable and consistent responses to the subsequent items. The full version of the survey is reported in the Appendix *(appendix n.1)* to ensure transparency and facilitate replicability of the study.

4.2.2 Sampling and data collection

Participants were recruited by contacting professionals working in the food sector, primarily via the LinkedIn platform. In total, 128 responses were collected. One response was excluded because the participant did not report working in the food, beverage, or packaging segments (resulting in a final dataset of N = 127 valid cases). In addition, 28 respondents provided qualitative comments in the optional open-ended field; these comments were exported and stored separately to support a complementary qualitative discussion at the end of the results section.

4.2.3 Data preparation

Survey data were exported to a spreadsheet format and cleaned prior to analysis. Categorical variables were standardized and encoded, and Likert-scale items were checked for consistency: items capturing negative psychological outcomes (Q11-Q15) were reverse-coded (6 − response value) to ensure that higher scores consistently indicate higher levels of wellbeing. In the case of the "department/functional area" variable (Q2), the questionnaire initially included five predefined categories and an "other - please specify" option.

Open-text responses were systematically reviewed and classified by aggregating highly specific roles into functionally coherent macro-categories. Responses were either assigned to existing categories or, when recurring patterns were identified, grouped into newly created categories, including managerial/business functions and R&D activities. As a result, the final categorical variable used in the analysis included seven department categories, ensuring a more accurate representation of the organizational functions within the sample.

The final dataset was then used for (i) descriptive statistics and subgroup comparisons in Python and (ii) PLS-SEM modelling (including multi-group analyses) in SmartPLS, as described in the following sections.

5. Descriptive Analysis

The final dataset consisted of 127 valid responses collected from professionals operating in the food industry. Before conducting the structural modelling analysis, a descriptive examination of the dataset was performed to characterize the sample and explore preliminary patterns among the study variables. Descriptive statistics and subgroup comparisons were computed using Python, based on the cleaned dataset derived from the survey responses.

5.1 Sample Characteristics

Table 5 reports the sample profile, presenting the distribution of the profiling variables (Q1-Q5) in terms of frequencies and percentages.

Variable	Category	Frequency	Percentage
Sector (Q1)	Food	100	78,7%
	Beverage	16	12,6%
	Packaging	11	8,7%
Department (Q2)	Production	22	17,3%
	Quality Control	44	34,6%
	Logistics	14	11,0%
	Maintenance	9	7,1%
	Administration/corporate	7	5,5%
	Business/Commercial	8	6,3%
	R&D	23	18,1%
Experience (Q3)	<1 years	7	5,5%
	1-3 years	28	22,0%
	4-7 years	40	31,5%
	8-15 years	23	18,1%
	>15 years	29	22,8%
Company Size (Q4)	<50 employees	12	9,4%
	50-249 employees	19	15,0%
	250-1000 employees	33	26,0%
	>1000 employees	63	49,6%
Country (Q5)	Italy	120	94,5%
	Other	7	5,5%

Table 5: Sample profile

Most respondents operate in the core food production segment (78.7%), followed by beverage (12.6%) and packaging (8.7%), confirming the relevance of the dataset for the Food Industry 5.0 context.

With respect to functional roles, the sample is distributed across multiple departments, with the largest shares in quality control (34.6%), R&D (18.1%), and production (17.3%). This distribution is consistent with the study design, as survey participants were primarily recruited from technical and operational departments where Industry 5.0 technologies and automation systems are more implemented and relevant.

In terms of professional experience, sample individuals show heterogeneous tenure levels, with the largest group reporting 4-7 years of experience (31.5%), followed by more senior professionals with over 15 years of experience (22.8%).

Nearly half of respondents (49.6%) work in very large organizations (>1000 employees), while 26.0% are employed in firms with 250-1000 employees, indicating that most of the sample operates in structurally complex organizational contexts where Industry 5.0 investments are more likely to occur. This spread allows for comparison between big enterprises and small-medium enterprises (SMEs).

With respect to geographical distribution, the majority of food industry professionals declared Italy as their country of employment (94.5%). Although the research design was not geographically restricted, the predominance of Italian cases situates the empirical analysis primarily within the Italian food industry context. The small proportion of international observations (n = 7; 5.5%) was retained, as it does not affect the overall national orientation of the study. This was also verified during the analysis in SmartPLS.

5.2 Descriptive Statistics of Constructs

Composite variables were computed as the mean of their respective items for each construct: **Digital Exposure** (Q8-Q9), **Psychological Wellbeing** (Q10-Q15), **Physical Wellbeing** (Q16-Q19), **and Industry 5.0 Models** (Q20-Q25).

In Table 6 are reported the descriptive statistics of the main constructs.

Construct	Mean	Std. Dev.	Min	Max
Digital Exposure	3.16	0.92	1.00	5.00
Psychological Wellbeing	4.20	0.61	2.33	5.00
Physical Wellbeing	3.56	0.74	1.75	5.00
Industry 5.0 Models	4.30	0.48	2.67	5.00

Table 6: descriptive statistics

Digital Exposure shows a moderate mean value ($M = 3.16$), indicating an overall intermediate level of interaction with digital and Industry 5.0-related technologies. This pattern suggests that, within the Italian food industry, digital and Industry 5.0-related technologies are present but not yet pervasive, reflecting a transitional stage in which adoption remains uneven across organizations and roles. However, the relatively high standard deviation ($SD = 0.92$) reveals substantial variability in technological exposure across the sample.

Psychological Wellbeing presents a comparatively high average score ($M = 4.20$, $SD = 0.61$), while Physical Wellbeing reports a moderately high mean ($M = 3.56$, $SD = 0.74$). Both constructs display limited dispersion due to the lower standard deviation, indicating relatively consistent perceptions among respondents. These results suggest that, among the surveyed workers, psychological wellbeing is perceived as a less critical area for improvement compared to physical wellbeing.

Industry 5.0 Models Acceptance records the highest central tendency ($M = 4.30$, $SD = 0.48$), reflecting broad support for human-centered organizational approaches within the Food Industry 5.0 framework.

Overall, the descriptive results suggest generally positive perceptions of wellbeing and high level of agreement for the Industry 5.0 human-centered principles, while technological exposure levels appear more differentiated across respondents.

5.3 Group Comparisons (Descriptive Level)

After examining the sample distribution and the overall means of the main constructs, exploratory comparisons were conducted to determine whether wellbeing perceptions vary across selected contextual variables. Specifically, mean differences in Psychological and Physical Wellbeing were examined across company size (Q4), perceived Industry 5.0 presence (Q7), department (Q2), and professional experience (Q3).

At this stage the purpose is to identify preliminary patterns and potential contextual trends prior to the structural PLS-SEM analysis and so do not involve inferential testing since it's just descriptive.

With respect to company size, psychological wellbeing remains relatively stable across categories (ranging from 4.07 to 4.30), suggesting limited variation associated with organizational dimension. Physical wellbeing, however, shows a slight upward trend in larger firms, increasing from approximately 3.50 in smaller companies to around 3.70 in larger organizations.

When grouping professionals according to perceived Industry 5.0 presence (Q7), a clearer pattern emerges. Psychological wellbeing increases from 3.95 among individuals reporting low technological presence to 4.37 among those perceiving moderate to high levels of Industry 5.0 integration. A similar trend is observed for physical wellbeing, which rises progressively from 3.02 to 3.80 across higher presence categories. This trend indicates that perceived technological maturity may contribute to more positive wellbeing perceptions, possibly by improving work organization, process reliability, and ergonomic conditions.

Across departments, moderate variability is observed. Technical and operational functions, such as production and quality control, exhibit modestly different physical wellbeing means compared to administrative or commercial roles. However, differences remain limited and do not reveal a systematic directional trend.

Finally, psychological wellbeing appears relatively stable across experience levels (approximately 4.12-4.27), whereas physical wellbeing reveals minor fluctuations without a clear monotonic trend.

Overall, these exploratory comparisons suggest that perceived technological presence and organizational context may be more relevant differentiating factors than demographic characteristics. These preliminary observations provide contextual grounding for the subsequent structural and multi-group analyses.

5.4 Correlation Analysis

Table 7 reports Pearson correlations among the main constructs.

	Industry 5.0 Models	Digital Exposure	Psychological Wellbeing	Physical Wellbeing
Industry 5.0 Models	1	0,10	-0,04	0,27
Digital Exposure	0,10	1	0,13	0,22
Psychological Wellbeing	-0,04	0,13	1	0,24
Physical Weelbeing	0,27	0,22	0,24	1

Table 7: Correlation Matrix

Correlations range from weak to moderate in magnitude ($r = -0.04$ to $r = 0.27$). Digital Exposure shows weak positive associations with Psychological Wellbeing ($r = 0.13$) and Physical Wellbeing ($r = 0.22$). Psychological and Physical Wellbeing are moderately correlated ($r = 0.24$), indicating partial overlap while preserving conceptual distinctiveness. These weak correlations suggest that digital exposure alone is insufficient to explain variations in wellbeing (especially for psychological), pointing to the role of additional organizational, contextual, and individual factors.

Industry 5.0 Models Acceptance is positively associated with Physical Wellbeing ($r = 0.27$) but shows no meaningful linear relationship with Psychological Wellbeing ($r = -0.04$). The association between Digital Exposure and Industry 5.0 Models Acceptance is weak ($r = 0.10$).

Overall, the relatively modest magnitude of bivariate correlations suggests that simple linear associations do not fully capture the complexity of relationships among constructs. This provides further justification for the use of PLS-SEM, which enables simultaneous estimation of latent relationships within a multivariate framework.

5.5 Exploratory Analysis of Industry 5.0 Models (RQ3)

To address RQ3, this study includes a dedicated focus on the perception of Industry 5.0 organizational solutions. Rather than identifying new models, which are discussed in Section 2 (background), the aim of this analysis is to explore workers' and practitioners' attitudes toward existing human-centered principles, and to assess which approaches are perceived as more relevant, acceptable, or desirable in practice. In this sense, RQ3 does not aim to evaluate the effectiveness of specific I5.0 principles, but to assess organizational readiness and cultural alignment with the human-centered vision of Industry 5.0, as perceived by workers operating in food industry contexts. This focus is particularly relevant in a sector that is progressively evolving toward Industry 5.0, where organizational readiness and acceptance may play a critical role in shaping successful implementation.

For this reason, the analysis of Industry 5.0 model acceptance is primarily descriptive in nature and is not included in the PLS-SEM framework, as the objective is not to examine causal relationships between this construct and other variables, but to provide contextual and interpretative insights into human-centered transformation within the food industry. Accordingly, this analysis is based on descriptive statistics and exploratory comparisons conducted using Python.

The objective of this analysis was threefold:
(i) to investigate which specific human-centered principles receive stronger endorsement,
(ii) to assess whether acceptance varies according to technological awareness and exposure, and
(iii) to explore potential contextual differences across organizational settings.

5.5.1 Item-Level Analysis

First, item-level statistics were examined to identify differences across the six dimensions composing the construct. Results indicate consistently high levels of agreement across most items. The highest mean is observed for the importance of privacy protection (Q22, $M = 4.71$), followed by balance between efficiency and wellbeing (Q20, $M = 4.43$) and maintaining a human-in-the-loop approach (Q23, $M = 4.40$). The lowest mean is associated with worker involvement in decision-making processes (Q24, $M = 3.85$), which also shows the highest dispersion, indicating greater variability in perceptions. This finding may reflect organizational constraints or limited opportunities for participatory decision-making in technologically evolving food industry contexts, particularly within smaller or less structured firms.

These findings suggest that while core human-centered principles are generally well received, participatory governance mechanisms may be perceived less uniformly across contexts.

5.5.2 Association with Industry 5.0 Knowledge and Presence

Second, correlations were computed between Industry 5.0 Models Acceptance and both Industry 5.0 knowledge (Q6, $p = 0.086$) and perceived technological presence (Q7, $p = 0.133$). Correlation coefficients are weak, indicating that agreement of human-centered organizational principles is only marginally associated with respondents' awareness or direct experience of Industry 5.0 technologies. This suggests that support for Industry 5.0 models may reflect a normative orientation rather than being strongly driven by technological exposure. In practical terms, this suggests that workers support human-centered principles as desirable future directions, even when they are not yet fully integrated into daily operational practices.

5.5.3 Group Comparisons

As a final step, group comparisons were conducted to explore whether acceptance levels vary across organizational contexts. Employees that work in large organizations (>1000 employees) report significantly higher acceptance level compared to those in small and medium enterprises (<250 employees).

Similarly, respondents reporting high digital exposure (Q8 values 4-5) and high perceived Industry 5.0 presence (Q7 values 4-5) display higher mean levels of Industry 5.0 Models Acceptance compared to their low-exposure counterparts (values 1-2). However, statistical significance is observed only for digital exposure (Q8), while differences related to perceived Industry 5.0 presence (Q7) are not statistically significant. Detailed results are reported in Table 8:

Comparison Variable	Group	Mean	t-statistic	p-value
Company Size	Large (>1000 employees)	4.39	2.02	0.048
	SMEs (<250 employees)	4.17		
Digital Exposure (Q8)	High (4-5)	4.46	2.06	0.042
	Low (1-2)	4.26		
Industry 5.0 Presence (Q7)	High (4-5)	4.39	1.16	0.250
	Low (1-2)	4.29		

Table 8: Group comparison for RQ3

Overall, results indicate widespread normative support for Industry 5.0 human-centered models, with stronger acceptance observed among respondents operating in technologically intensive and structurally larger organizational contexts.

6. Partial Least Squares Structural Equation Modeling

To examine the structural relationships between digital exposure and workers' wellbeing within the Food Industry 5.0 framework, Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed. PLS-SEM is a variance-based structural modelling technique particularly suitable for exploratory research contexts, prediction-oriented objectives, and models involving latent constructs measured through multiple reflective indicators.

The adoption of PLS-SEM is justified by several methodological considerations [41]. Given the exploratory nature of the study and the emerging, heterogeneous character of the Industry 5.0 context, a variance-based structural modeling approach is particularly appropriate. Moreover, the sample size (N = 127) satisfies commonly accepted adequacy criteria for PLS-SEM applications. As a distribution-free method, PLS-SEM does not require multivariate normality, making it well suited for the analysis of Likert-scale survey data. Finally, the study primarily aims to explain and predict relationships among constructs rather than to test a fully established covariance-based theoretical model.

All analyses were conducted using SmartPLS, which enables estimation of measurement and structural models, bootstrapping procedures, and permutation-based multi-group analyses.

6.1 Measurement Model Specification

6.1.1 Reflective Measurement Specification

All constructs were specified as reflective. The observed indicators are conceptualized as manifestations of their respective latent constructs. Variations in the underlying latent variable are therefore expected to produce systematic changes across its indicators. This specification is theoretically consistent, as constructs such as psychological and physical wellbeing represent latent states that influence respondents' perceptions across multiple related items.

6.1.2 Assessment of Common Method Bias

Given that all variables were collected through a single self-reported questionnaire, potential common method bias (CMB) was assessed using Harman's single-factor test. A principal component analysis including all Likert-scale items was conducted. The first unrotated factor accounted for 25.85% of the total variance, well below the commonly suggested threshold of 50% [42]. This result indicates that common method bias is unlikely to substantially affect the findings.

6.2 PLS-SEM Models

To empirically test RQ1 and RQ2, a structural model was specified in which Digital Exposure acts as an exogenous construct predicting two endogenous constructs: Psychological Wellbeing and Physical Wellbeing. The model operationalizes the assumption that interaction with digital technologies may influence both psychological and physical dimensions of workers' wellbeing within the Food Industry 5.0 context.

RQ1: DIGITAL EXPOSURE → PSYCHOLOGICAL WELLBEING

RQ2: DIGITAL EXPOSURE → PHYSICAL WELLBEING

Digital Exposure was measured using Q8 (technology interaction) and Q9 (technology training), while Physical Wellbeing was measured using Q16-Q19. Two alternative specifications were estimated for Psychological Wellbeing to assess measurement robustness.

Full Model

In the full specification, Psychological Wellbeing was measured using items Q11-Q15 as illustrated in figure 2.

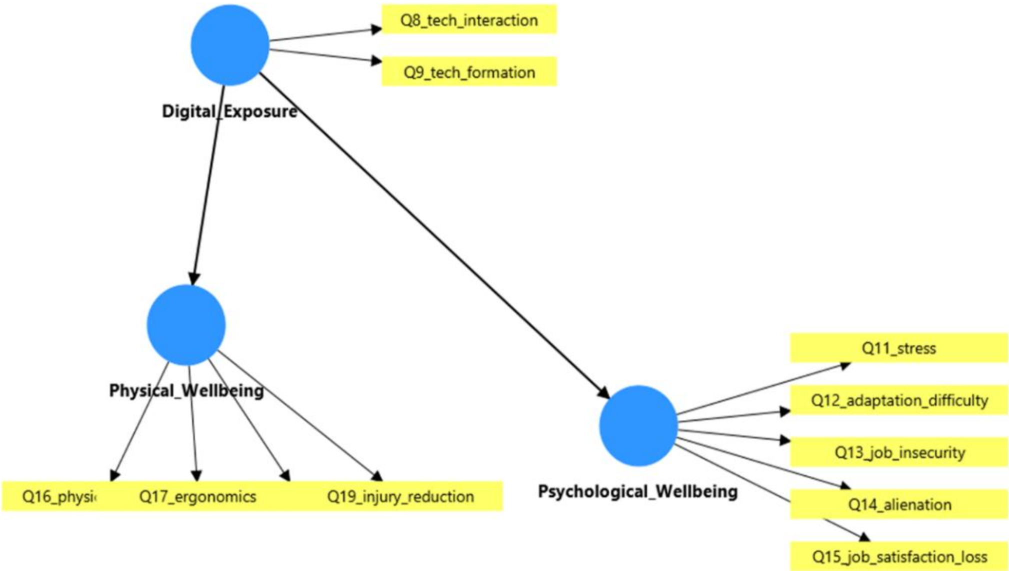


Figure 2: Full model from the SmartPLS report

Reduced Model

Assessment of outer loadings in the full model revealed very low loadings for Q11 (0.169) and Q12 (0.120), which substantially reduced convergent validity. For this reason, a reduced model excluding these items was estimated. The reduced specification focuses on items capturing deeper psychological dimensions such as job insecurity, alienation, and loss of satisfaction. Therefore, in the reduced specification, Psychological Wellbeing was operationalized using only Q13-Q15 as shown in figure 3.

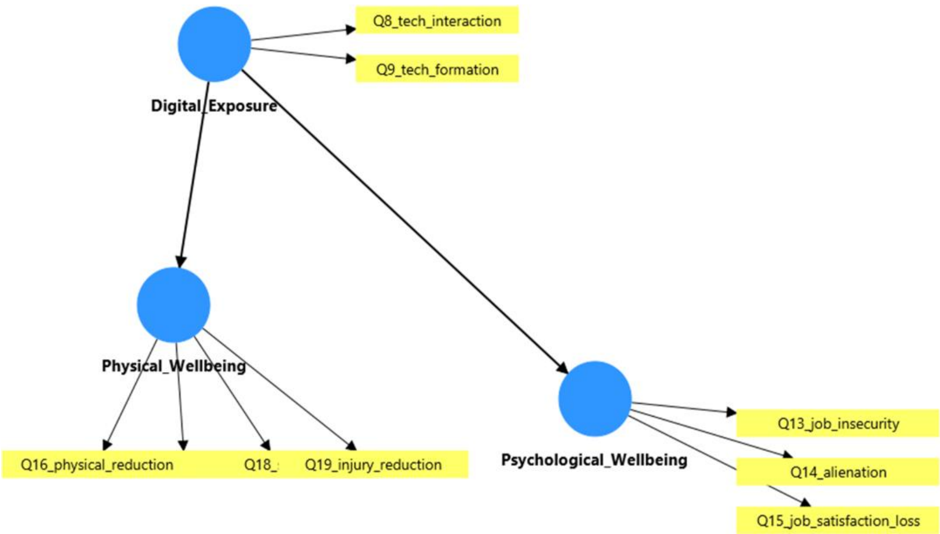


Figure 3: Reduced model from SmartPLS report

Item Q10 was excluded from both specifications because it captures perceived work efficiency rather than psychological wellbeing in terms of stress, alienation, or insecurity. Conceptually, Q10 reflects performance perception rather than psychological experience and its inclusion generated weak measurement performance.

6.3 Measurement Model Assessment

Before assessing the structural relationships, the measurement model was evaluated to ensure adequate reliability and validity of the latent constructs. Following established PLS-SEM guidelines [41], indicator reliability, convergent validity, internal consistency, and discriminant validity were examined.

✓ Outer Loadings (Reliability)

Indicator reliability was assessed through outer loadings. Digital Exposure and Physical Wellbeing indicators exhibited satisfactory loadings in both model specifications. In contrast, the Psychological Wellbeing construct showed weak indicator reliability in the full model, particularly for items Q11 and Q12, whose loadings were substantially below recommended thresholds. These low loadings reduced convergent validity and motivated the estimation of a reduced model excluding these items.

✓ Convergent Validity and Consistency

Convergent validity was assessed using Average Variance Extracted (AVE), while internal consistency reliability was evaluated through Composite Reliability (ϱc) and Cronbach's alpha. Table 9 reports the measurement model results.

Construct	Model	AVE	Composite Reliability (ρc)	Cronbach's α
Psychological Wellbeing	Full	0.320	0.621	0.767
Psychological Wellbeing	Reduced	0.522	0.749	0.821
Physical Wellbeing	Both	0.531	0.818	0.749
Digital Exposure	Both	≈ 0.58	≈ 0.72	0.341

Table 9: Measurement Model Assessment

In the full specification, Psychological Wellbeing does not meet the recommended AVE threshold of 0.50, indicating insufficient convergent validity. In the reduced model, AVE increases to 0.522 and composite reliability improves to 0.749, supporting the use of the reduced model as the primary specification for structural inference.

Physical Wellbeing and Digital Exposure meet recommended thresholds in both specifications. The relatively low Cronbach's alpha for Digital Exposure reflects the two-indicator nature of the construct; therefore, composite reliability and AVE are considered more appropriate indicators of internal consistency.

✓ Discriminant Validity

Discriminant validity was examined using the Fornell-Larcker criterion and the heterotrait–monotrait (HTMT) ratio as provided by the SmartPLS output. No critical issues were observed, indicating adequate discriminant validity among the constructs.

6.4 Bootstrapping

After ensuring the adequacy of the measurement model, the structural relationships were assessed using a bootstrapping procedure. Bootstrapping with 5,000 resamples was conducted to evaluate the statistical significance of the estimated path coefficients, as recommended in PLS-SEM for inference testing.

✓ Path Coefficients (β)

Table 10 reports the structural path coefficients and their significance levels:

Path	Full Model (β)	p-value	Reduced Model (β)	p-value
Digital Exposure → Physical Wellbeing	0.276	0.003	0.274	0.002
Digital Exposure → Psychological Wellbeing	0.172	0.543	0.165	0.455

Table 10: Structural Model Results

Results indicate that Digital Exposure exhibits a positive and statistically significant relationship with Physical Wellbeing in both the full and reduced model specifications. In contrast, the relationship between Digital Exposure and Psychological Wellbeing does not reach statistical significance in either model.

These findings suggest differential effects of digital technologies across wellbeing dimensions, which are further discussed in the subsequent chapter.

✓ Coefficient of Determination (R^2)

The explanatory power of the model was assessed using the coefficient of determination (R^2). Table 11 reports the R^2 values for the endogenous constructs:

Endogenous Construct	Full Model	Reduced Model
Physical Wellbeing	0.076	0.075
Psychological Wellbeing	0.030	0.027

Table 11: Explained Variance (R^2)

R^2 values indicate modest explanatory power, particularly for Psychological Wellbeing. This outcome is consistent with the exploratory nature of the study and suggests that psychological outcomes may be influenced by additional organizational, contextual, or individual factors not included in the present model.

✓ Effect Size (f^2) and Collinearity

Effect sizes (f^2) were examined to assess the relative impact of Digital Exposure on the endogenous constructs. Results indicate a small-to-moderate effect on Physical Wellbeing ($f^2 \approx 0.081 - 0.083$) and a small effect on Psychological Wellbeing ($f^2 \approx 0.028 - 0.030$).

Collinearity was assessed through variance inflation factor (VIF) values. All VIF values equal 1.0, indicating no multicollinearity concerns among the structural paths.

Overall, the structural model results suggest that digital exposure is more strongly associated with perceived physical aspects of work than with psychological dimensions.

6.5 Multi Group Analysis (MGA)

Permutation-based multi-group analysis (MGA) was conducted using the reduced model to explore whether structural relationships differ across subgroups. This step is particularly important given the heterogeneous nature of the sample, as respondents operate in different organizational contexts, roles, and levels of technological exposure. MGA therefore supports a clearer interpretation of the results by accounting for differences across organizational contexts within the Food Industry 5.0 environment.

Three group comparisons were performed:

1. **Department (Q2)**
   Production and Quality Control departments were compared against all other functions.
2. **Company Size (Q4)**
   Large organizations (>1000 employees) were compared against small and medium firms (<250 employees).
3. **Digital Exposure Level (Q8)**
   Respondents reporting high exposure (values 4-5) were compared with those reporting low exposure (values 1-2).

Department (Q2)

The difference in the Digital Exposure → Physical Wellbeing path approaches significance ($p = 0.0736$), suggesting a potential trend toward stronger effects in technical and operational departments. No significant difference emerges for Psychological Wellbeing ($p = 0.297$).

Company Size (Q4)

No statistically significant differences are observed between large and smaller firms for either structural path ($p = 0.526$ for Physical Wellbeing; $p = 0.189$ for Psychological Wellbeing). Organizational scale alone does not appear to meaningfully moderate the relationships under investigation.

Digital Exposure Level (Q8)

A statistically significant difference is observed for the Digital Exposure → Physical Wellbeing path ($p = 0.0062$), indicating that the relationship is stronger among respondents reporting higher levels of technological exposure. No significant difference emerges for Psychological Wellbeing ($p = 0.730$).

These findings suggest that technological intensity may amplify perceived physical benefits, whereas psychological perceptions appear less sensitive to subgroup differences within the present sample.

7. Discussion of Results

This study explores the relationship between digital exposure and workers' wellbeing within the Food Industry 5.0 context, combining descriptive analysis, PLS-SEM modelling, multi-group analysis, and qualitative insights.

The results reveal three main patterns. First, digital exposure shows a statistically significant and positive association with physical wellbeing, while no significant structural relationship emerges with psychological wellbeing. Second, acceptance of Industry 5.0 human-centered models is consistently high across the sample. Third, the effects of digital technologies appear to be context-dependent, varying across exposure levels, company size, and operational roles.
Overall, findings suggest that within the Italian food industry context, digital technologies are not perceived as a systemic psychological threat, while their physical implications are more clearly recognized.

7.1 Digital Exposure and Psychological Wellbeing (RQ1)

With respect to psychological wellbeing, the structural model does not provide statistical evidence of a direct relationship between digital exposure and psychological outcomes. Although small variations emerge at the descriptive level when comparing subgroups, these differences do not translate into statistically significant effects in the structural model. It should also be noted that psychological wellbeing represents a complex and highly subjective construct. Item-level analyses reveal heterogeneous patterns, with some indicators capturing stronger perceptions than others. This complexity is reflected in the initial full model, where some items showed weak loadings, which led to the use of a reduced model focusing on the most relevant psychological aspects.

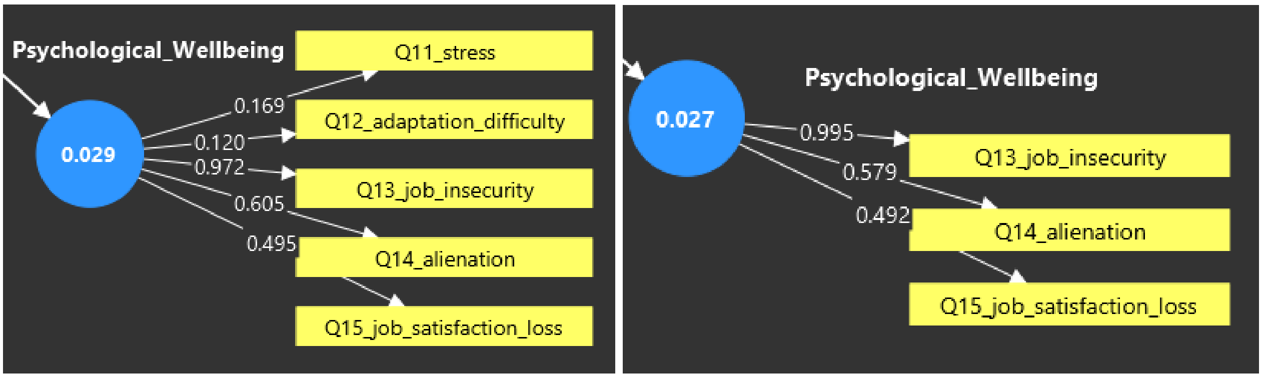
Furthermore, the items included in the psychological wellbeing construct were primarily designed to capture negative psychological dimensions associated with excessive automation, such as alienation, job insecurity, and stress. Across the sample, these items generally received low scores, indicating that only a limited number of respondents reported negative psychological experiences related to the use of digital technologies.

Several explanations can be advanced. The psychological impact of digital technologies appears to depend less on the level of exposure itself and more on how technologies are introduced and managed within organizations. Factors such as organizational culture, managerial practices, and change management strategies may therefore play a key role in shaping workers' psychological experiences. Additionally, the level of technological integration within the Italian food sector may still be partial or in some cases absent, as many food companies have not yet fully adopted advanced digital technologies, limiting the emergence of systemic psychological disruption. This interpretation is consistent with the national context, characterized by a high prevalence of small and medium-sized enterprises and by a gradual uptake of Industry 5.0-related investments.

Qualitative comments further support this interpretation *(appendix 2)*. Many respondents emphasized the importance of training, gradual implementation, and preserving human centrality, repeatedly stating that technology "should not replace human activity" and must be "tailored to the production context." Overall, concerns were more frequently directed toward how technologies are implemented and managed rather than toward the technologies themselves.

In this regard, feedback received from a respondent working in maintenance highlighted how highly automated systems, when lacking redundancy and adequate service coverage, may generate stress due to production stoppages and increased workload during failures. This example illustrates how psychological strain may arise from organizational vulnerabilities associated with automation rather than from technological exposure alone.

Taken as a whole, these findings indicate that psychological wellbeing in digitally evolving food industry contexts is less influenced by the intensity of technological exposure and more by how technologies are integrated, governed, and supported within organizational systems. In the Italian food sector, where technological adoption remains uneven and the transition toward advanced automation is still in progress, psychological outcomes appear to depend strongly on organizational readiness, implementation quality, and support mechanisms rather than on technological intensity alone.
Figure 5 illustrates the standardized outer loadings of the Psychological Wellbeing construct across the two model specifications estimated in SmartPLS. The comparison between the full model (Q11-Q15) and the reduced model (Q13-Q15) highlights substantial differences in item relevance.



(a) Full Model (b) Reduced Model

Figure 5: Outer Loadings of Psychological_Wellbeing Construct (SmartPLS)

7.2 Digital Exposure and Physical Wellbeing (RQ2)

The structural model indicates a positive and statistically significant relationship between digital exposure and physical wellbeing in both model specifications. Although the explained variance is modest, the direction and consistency of the effect suggest that increased interaction with digital technologies is associated with improved perceptions of physical working conditions.
This finding is coherent with both the descriptive results and several qualitative comments provided by respondents *(appendix 2)*. Multiple participants explicitly referred to automation as a means to reduce physically demanding tasks, night shifts, repetitive manual operations, and ergonomic risks. References to collaborative robots (cobots), automated storage systems, and reduction of production waste illustrate how technology is perceived as alleviating physical strain.

The qualitative responses reinforce this interpretation. Several participants described automation as particularly beneficial in repetitive or physically intensive processes, highlighting improved safety and workload reduction. This convergence between quantitative and qualitative evidence strengthens the interpretation that, within this context, technological integration is primarily perceived as a tool for improving physical aspects of work. As illustrated in the figure below, higher levels of digital exposure are associated with higher perceived physical wellbeing. This pattern is consistent with a context such as the Italian food industry, which is still progressively evolving toward Industry 4.0 and Industry 5.0 paradigms, where digital technologies are primarily introduced to reduce physical workload while improving efficiency of the processes.

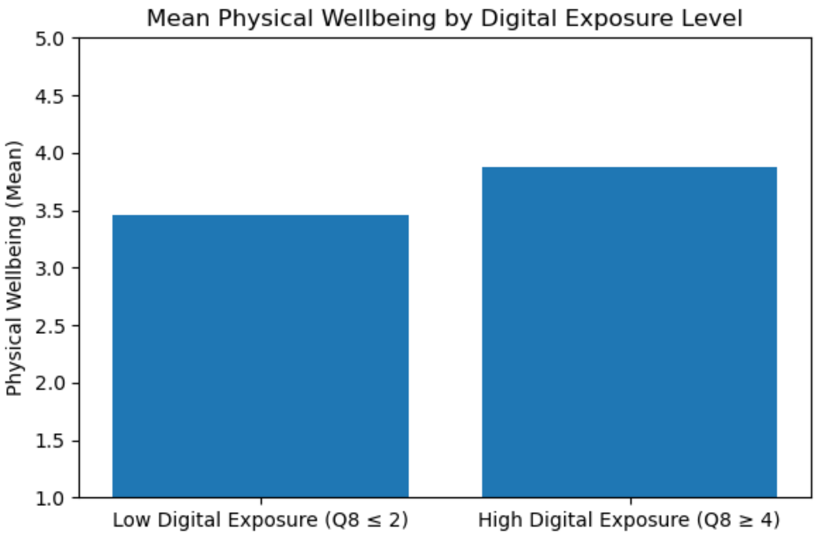


Figure 4: Mean of Physical Wellbeing in different Digital scenarios (Python)

7.3 Industry 5.0 Models Acceptance (RQ3)

RQ3 is addressed by examining workers' perceptions and acceptance of key human-centered organizational principles associated with Industry 5.0, rather than by providing an exhaustive classification of I5.0 models. This approach allows assessing whether such principles are perceived as relevant and feasible within the current Food Industry 5.0 context, particularly in relation to the balance between technological efficiency and human centrality.

The exploratory analysis of Industry 5.0 Models Acceptance reveals consistently high levels of agreement across the sample. Principles related to privacy protection, balance between efficiency and wellbeing, and human-in-the-loop approaches receive particularly strong endorsement. By contrast, worker involvement in decision-making processes, while still positively evaluated, shows greater variability, suggesting less uniform implementation or experience across organizations.

Interestingly, acceptance of Industry 5.0 human-centered principles is only weakly related to respondents' knowledge of Industry 5.0 or to the perceived presence of advanced digital technologies. This suggests that support for human-centered Industry 5.0 models is driven more by shared values and expectations than by direct daily experience with advanced technologies. Even though the Italian food industry is still uneven in terms of Industry 4.0 and 5.0 implementation, professionals appear ready and receptive to this transition.

Qualitative comments strongly reinforce this interpretation *(appendix 2)*. Many respondents emphasized the importance of continuous and targeted training, the preservation of human expertise and creativity, and the need to avoid forced substitution of human activities with automated processes. Several participants highlighted that technology should act as a support tool rather than a replacement for human know-how and decision-making. At the same time, multiple comments pointed to structural limitations of the Italian industrial context, characterized by a strong presence of small and medium-sized enterprises. In this setting, technological integration is often described as gradual or constrained by limited internal competencies and investment capacity.

Taken together, these findings address RQ3 by showing that Industry 5.0–oriented organizational solutions, such as human-in-the-loop approaches, privacy-preserving monitoring, and a balance between efficiency and wellbeing, are generally perceived as desirable by workers. At the same time, the more heterogeneous evaluation of participatory practices indicates that the implementation of human-centered models is still uneven across contexts. Rather than identifying a single optimal solution, this study highlights the conditions under which human-centered principles are more likely to be accepted in practice, namely organizational readiness, investment in training, and the ability to adapt technologies to specific production contexts.

Figure 5 illustrates the mean agreement levels for the individual Industry 5.0 Models Acceptance items (Q20-Q25).

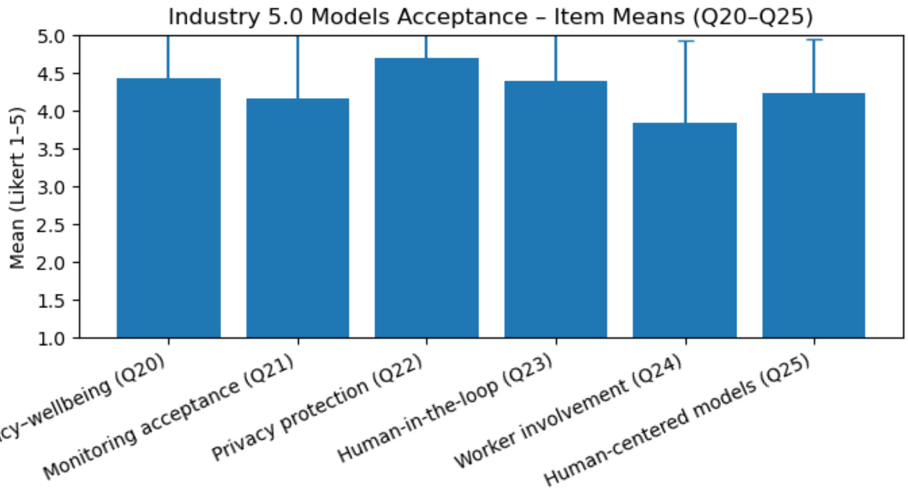


Figure 5: Means of the Industry 5.0 models items: Q20-Q25 (Python)

7.4 Contextual Heterogeneity: Multi-Group Analysis

Multi-group analysis further reinforces the notion that the impact of digital technologies on workers' wellbeing is not uniform across organizational contexts. Rather than introducing new effects, MGA helps clarify under which conditions previously observed relationships become more relevant.

Before discussing subgroup differences in detail, it is important to interpret MGA results in light of the overall structural findings. In particular, the absence of a significant main effect between digital exposure and psychological wellbeing may partly explain why subgroup differences for this relationship do not consistently reach conventional significance thresholds. This does not exclude the possibility that psychological outcomes remain sensitive to contextual and organizational conditions, as also suggested by descriptive analyses, but indicates that such effects are not sufficiently captured by the structural relationship examined in this study.

By contrast, more informative patterns emerge for physical wellbeing. The comparison between high and low digital exposure groups shows that a positive relationship between digital exposure and physical wellbeing is stronger in contexts where digital technologies are more extensively used. Differences across departments approach statistical significance but remain below conventional thresholds ($p - value < 0.05$). Nevertheless, qualitative insights indicate that operational and technical departments, where digital technologies and automated systems are used more extensively in daily work activities, are the contexts in which different impacts on workers' wellbeing are more likely to emerge.

Differences related to organizational characteristics also emerge when considering Industry 5.0 model acceptance. Large organizations display significantly higher acceptance levels compared to small and medium-sized enterprises, a pattern consistent with qualitative feedback emphasizing greater investment capacity, availability of internal competencies, and higher levels of technological maturity.

Taken together, these results confirm that the relationship between digital technologies and wellbeing is highly context-dependent and influenced by organizational structure, technological intensity, and functional roles.

7.5 Theoretical Implications

The study contributes to the emerging Industry 5.0 literature in three main ways.

First, it differentiates between physical and psychological dimensions of wellbeing, showing that technological exposure may exert distinct effects across these domains. While physical benefits appear more directly observable, psychological outcomes are more complex and potentially mediated by organizational processes.

Second, the results are not sufficient to conclude that high exposure to digital technologies and automation leads to psychological stress, alienation, or fear of job replacement. At the same time, the opposite conclusion cannot be drawn. These findings highlight the importance of carefully considering the specific industrial and organizational context before making generalized claims about the psychological impact of digital transformation.

Third, the results highlight the importance of contextual heterogeneity. Company size, exposure intensity, and organizational structure influence how technology interacts with wellbeing, suggesting that future research should adopt multi-level or moderated frameworks.

7.6 Practical Implications

From a managerial and organizational perspective, this study offers several relevant insights for companies operating in the food industry. The findings highlight the importance of public support mechanisms and governmental incentives in facilitating technological investments. Without adequate financial support, the adoption of advanced digital technologies may remain limited, reducing the potential positive effects on both physical and psychological wellbeing. In this sense, policy instruments such as national Industry 5.0 incentive schemes play a crucial enabling role.

At the same time, while physical wellbeing emerges as the dimension most directly associated with digital exposure in this study, psychological wellbeing should not be overlooked. As technological integration advances, particularly in larger and more structured organizational contexts, psychological outcomes may become increasingly relevant. Managers should therefore adopt a balanced approach, recognizing that physical improvements alone are not sufficient to ensure overall worker wellbeing.

In addition, the consistently high acceptance of Industry 5.0 human-centered models suggests that the workforce is generally receptive to these paradigms. This creates an important opportunity for organizations to invest in human capital through training, skill development, and continuous learning, ensuring that technological innovation is perceived as supportive rather than disruptive.

However, the relatively lower emphasis placed on worker involvement points to a critical area for improvement. In several organizational contexts, limited participation may reflect a lack of awareness or understanding of ongoing technological changes, which can reduce engagement. Managers therefore play a key role in fostering involvement by increasing transparency and actively engaging employees in the change process. Where feasible, practices such as job enlargement, job enrichment, and job rotation can further support this process by broadening skills, increasing autonomy, and reducing dependency on a limited number of roles. This is particularly relevant in the food industry, where complex supply chains, tight production schedules, and high automation levels may amplify stress during disruptions. Strengthening worker involvement and cross-functional competencies may thus enhance both acceptance of technological change and organizational resilience.

In summary, these findings suggest that successful implementation of Industry 5.0 technologies requires not only technological investment but also coordinated organizational strategies. Tailored solutions, adequate training, and thoughtful change management practices are essential to translate technological innovation into tangible wellbeing benefits within heterogeneous food industry environments.

8. Conclusions

This research set out to examine how digital technologies associated with Industry 5.0 influence workers' wellbeing within the food industry, with particular attention to the Italian context. By integrating quantitative analysis with qualitative insights, the study provides empirical evidence on a topic that remains underexplored in current Food Industry 5.0 research.

The findings highlight a clear distinction between physical and psychological wellbeing outcomes. While digital exposure is positively associated with perceived physical wellbeing, no direct statistical relationship emerges with psychological wellbeing. This suggests that, at the current stage of technological adoption, digital technologies in the Italian food industry are primarily perceived as tools for reducing physical strain and improve efficiency rather than as sources of psychological risk or benefit.

At the same time, the consistently high acceptance of human-centered Industry 5.0 principles indicates strong alignment between workers' values and the normative vision of Industry 5.0. Although workers show a high level of acceptance of human-centered Industry 5.0 principles, these principles are not yet fully reflected in everyday work practices. This suggests that organizational aspects, such as training, governance, and change management, play a key role in translating human-centered visions into concrete workplace experiences.

Overall, this study confirms that the impact of digital technologies on wellbeing is highly context-dependent. As the food industry continues to evolve toward more advanced Industry 5.0 configurations, future efforts should focus not only on technological investment but also on organizational readiness and human-centered integration to ensure sustainable and inclusive digital transformation.

8.1 Limits and Future works

This study has several limitations that should be acknowledged and that also open avenues for future research.

The research adopts a quantitative, empirical approach aimed at analyzing relationships between digital technologies and workers' wellbeing within the Food Industry 5.0 context. While the analysis relies on statistical modeling and empirical data, it does not seek to establish definitive causal relationships or universal generalizations. The findings should therefore be interpreted as context-specific and indicative, contributing to the understanding of observed patterns rather than providing conclusive evidence.

The sample size represents an important limitation. Although the final dataset includes 127 valid responses and is suitable for PLS-SEM analysis, a larger sample would be necessary to increase statistical power and robustness. Future studies would benefit from larger datasets to enable more reliable group comparisons and to better capture heterogeneity across organizational contexts and roles.

Sample heterogeneity constitutes both a strength and a limitation. While respondents operate in diverse organizational settings, this diversity reduces the possibility of conducting in-depth contextual analyses. Future research could benefit from closer collaboration with one or more organizations, preferably larger firms within the sector, as this would allow the collection of richer and more homogeneous data. Such collaborations would enable a more comprehensive and context-sensitive investigation, supported by direct interactions with industry experts and by a closer examination of actual working environments and operational workflows.

In addition, the timing of the study represents an additional constraint. The Italian food industry is still in a transitional phase toward Industry 5.0, characterized by uneven technological adoption and a strong presence of small and medium-sized enterprises. As a result, some findings may reflect early-stage dynamics rather than fully developed Industry 5.0 conditions.

Despite these limitations, the findings of this study provide a valuable starting point for future research by offering initial empirical evidence on the wellbeing implications of Industry 5.0 in the food sector.

Acknowledgements

The author gratefully acknowledges the supervision and valuable guidance of Prof. Di Francesco, as well as the time and valuable contributions of all survey respondents.

References

[1] K. Majumdar, A. K. Verma, K. V. Kathpalia, P. Samajder e P. K. Prabhakar, «Utilizing Industry 5.0 Technologies to Improve Food Production and Promote Sustainability in Agriculture,» in *Food and Industry 5.0: Transforming the Food System for a Sustainable Future*, 2025, pp. 143-153.

[2] K. A. Singh, F. Patra, T. Ghosh, N. K. Mahnot, H. Dutta e R. K. Duary, «Advancing food systems with industry 5.0: A systematic review of smart technologies, sustainability, and resource optimization,» *Sustainable Futures,* 2025.

[3] F. Venturi, A. Tonacci, R. Ascrizzi, F. Sansone, R. Conte, A. P. Pala, A. Tarabella, C. Sanmartin, I. Taglieri, R. Marangoni, M. Bietresato, P. Comuzzo, R. Zironi, A. Zironi, G. Ciotti e R. Gubiani, «"CANTINA 5.0"—A Novel, Industry 5.0-Based Paradigm Applied to the Winemaking Industry in Italy,» *Applied Sciences,* vol. 14, n. 11, 2024.

[4] European Commission: Directorate-General for Research and Innovation, «Industry 5.0 – Towards a sustainable, human-centric and resilient European industry,» *Publications Office of the European Union,* 2021.

[5] N. Vanitha, «Exploring the Fusion: Applications and Challenges of Integrating Food Technology with Big Data and Industry 5.0,» in *Food and Industry 5.0: Transforming the Food System for a Sustainable Future*, 2025, pp. 131-142.

[6] FAO (Food and Agriculture Organization), «The future of food and agriculture – Alternative pathways to 2050. Summary version.,» 2018.

[7] J. H. Trienekens, «Agricultural value chains in developing countries a framework for analysis,» *International food and agribusiness management review,* vol. 14, n. 2, pp. 51-82, 2011.

[8] FAO (Food and Agriculture Organization), «Making agrifood systems more resilient to shocks and stresses,» *The State of Food and Agriculture,* 2021.

[9] N. García, F. Lema, C. Rosero-Mantilla, C. Sánchez, E. Tubón-Nuñez, L. Morales, P. Córdova, L. Siguenza-Guzman, E. Sigcha e F. Tigre, «Indicators for the Evaluation of Agri-Food Supply Chains Under Industry 5.0 Parameters,» in *Advanced Research in Technologies, Information, Innovation and Sustainability*, 2025, pp. 20-36.

[10] M. Trstenjak, T. Opetuk, G. Đukić e H. Cajner, «Logistics 5.0 Implementation Model Based on Decision Support Systems,» *Sustainability,* vol. 14, n. 11, 2022.

[11] A. Hassoun, S. Jagtap, H. Trollman, G. Garcia-Garcia, L. N. K. Duong, P. Saxena, Y. Bouzembrak, H. Treiblmaier, C. Para-López, C. Carmona-Torres, K. M. D. Dev e A. Aït-Kaddour, «From Food Industry 4.0 to Food Industry 5.0: Identifying technological enablers and potential future applications in the food sector,» *Comprehensive Reviews in Food Science and Food Safety,* vol. 23, n. 6, 2024.

[12] W. Been e M. Huisman, «Digital Transformation: A Threat to Meaningful Work?,» *Italian Labour Law E-Journal,* vol. 17, n. 2, pp. 29-44, 2024.

[13] Eurofound, «Implications of AI for work, employment and social dialogue: Literature review,» *European Foundation for the Improvement of Living and Working Conditions,* 26 September 2025.

[14] X. Liu e Y. Li, «Examining the Double-Edged Sword Effect of AI Usage on Work Engagement: The Moderating Role of Core Task Characteristics Substitution,» *Behavioral Sciences,* vol. 15, n. 2, 2025.

[15] F. Antonaci, E. Olivetti, F. Marcolin, I. Castiblanco Jimenez, B. Eynard, E. Vezzetti e S. Moos, «Workplace Well-Being in Industry 5.0: A Worker-Centered Systematic Review,» *Sensors,* vol. 24, 2024.

[16] M. H. Dehbozorgi, J. Postell, D. Ward, C. Leardi, B. P. Sullivan e M. Rossi, «Human in the loop: revolutionizing industry 5.0 with design thinking and systems thinking,» *Proceedings of the Design Society,* vol. 4, pp. 245-254, 2024.

[17] I. Muttaqin, «Human-Centered Ergonomic Design in Industry 5.0: Enhancing Productivity and Worker Wellbeing,» *Jurnal Riset Teknologi Pencegahan Pencemaran Industri,* vol. 16, n. 1, pp. 41-50, 2025.

[18] Ministero delle Imprese e del Made in Italy (MIMIT), «Piano Transizione 5.0,» 2024. [Online]. Available: https://www.mimit.gov.it/it/incentivi/piano-transizione-5-0.

[19] Mecse Bari, «Adoption of Industry 5.0 incentives in Italian manufacturing firms.,» 2025. [Online]. Available: https://www.mecspebari.it/en/press-release/intelligenza-artificiale-transizione-green-nuove-competenze-manifattura-italiana-sfide-futuro/.

[20] Industria5Punto0, «Transizione 5.0 in Italy: Incentives and technological innovation,» 2025. [Online]. Available: https://industria5punto0.eu/transizione-5-0-in-italia-maggio-2025-novita-legislative-incentivi-e-tecnologie/.

[21] Ecostar, «Industry 5.0 transition plan: Tax credits and incentives for digitalization and energy efficiency. Ecostar,» 16 July 2025. [Online]. Available: https://ecostar.eu.com/industry-5-0-transition-plan-tax-credits-and-incentives-for-digitalization-and-energy-efficiency/.

[22] M. S. M. Maharajan, T. P. B. Balakrishnan, M. A. Amanullah, G. G. D. Gayathiri Devi e A. P. Punitha, «Enhancing the Food Processing in Industry 5.0 Based on Artificial Intelligence,» *International Journal of INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING,* pp. 231-239, 2024.

[23] Invest in Italy, «Incentives for digital and green transition,» 2025. [Online]. Available: https://www.investinitaly.gov.it/index.php/en/doing-business/incentives.

[24] European Commission, «Industry 5.0: Industrial research and innovation,» 2026. [Online]. Available: https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/industry-50_en.

[25] Y. Iskandar, «Exploring Food Supply Chain Resilience: A Systematic Literature Review of Technology and Policy Strategies,» *Journal of Global Innovations in Agricoltural Sciences,* pp. 1143-1153, 2025.

[26] S. Guruswamy, M. Pojić, J. Subramanian, J. Mastilović, S. Sarang, A. Subbanagounder, G. Stojanović e V. Jeoti, «Toward Better Food Security Using Concepts from Industry 5.0,» *Sensors,* vol. 22, n. 21, 2022.

[27] S. Gaikwad e K. Anerao, «Industry 5.0 Innovations for Waste Management and Circular Economy in Sustainable Food systems: A systematic review,» *BIO Web of Conferences,* vol. 178, 2025.

[28] H. Trollman, «Feature extraction for artificial intelligence enabled food supply chain failure mode prediction,» *Discover Food,* vol. 4, n. 1, 2024.

[29] B. D. Sarkar, I. Sharma e V. Shardeo, «A multi-method examination of barriers to traceability in Industry 5.0-enabled digital food supply chains,» *The International Journal of Logistics Management,* 2024.

[30] V. Kumar, P. Verma, B. Shah e V. Kumar, «Redesigning short food supply chains for sustainable livelihoods and economies worldwide: a review of contributions from the British Food Journal,» *British Food Journal,* 2025.

[31] D. Singh e V. Cohen, «Socio-economic dimensions and human centricity in Industry 5.0: a study on manufacturing sectors in central and Eastern European economies,» *Journal of Economic Studies,* vol. 9, 2024.

[32] N. Kashchena, H. Chmil, O. Chumak, I. Nesterenko, A. Mykytas e Y. Chmil, «Assessing the effectiveness of innovative transformations of socioeconomic systems and enterprise development within Industry 5.0,» *Eastern-European Journal of Enterprise Technologies,* vol. 3, n. 13 (135), pp. 35-46, 2025.

[33] F. Fraile, F. Psarommatis, F. Alarcón e J. Joan, «A Methodological Framework for Designing Personalised Training Programs to Support Personnel Upskilling in Industry 5.0,» *Computers,* vol. 12, n. 11, 2023.

[34] I. Hansen, O. J. Mork, P. S. Kleppe e L. a. L. Giske, «Towards Industry 5.0: Developing Knowledge and Skills in a Research and Innovation Lab,» *European Conference on Knowledge Management,* vol. 24, n. 1, pp. 509-517, 2023.

[35] B. P. Argüello e V. González-Prida, «Integrating Change Management with a Knowledge Management Framework: A Methodological Proposal,» *Information,* vol. 15, n. 7, 2024.

[36] A. Corallo, M. E. Latino, M. Menegoli e F. Signore, «Digital Technologies for Sustainable Development of Agri-Food: Implementation Guidelines Toward Industry 5.0,» *IEEE Transaction on Engineering Management,* vol. 71, pp. 10699-10715, 2024.

[37] W. Guangju, F. Batool, S. Hussain, M. Jabeen, M. Ali e A. Afzal, «Impact of Industry 4.0 and 5.0 Technologies on Circular Economy and Sustainable Performance Using Hybrid PLS-SEM and ANN Approach,» *Human Behavior and Emerging Technologies,* 2025.

[38] L. Guo, D. Sun, M. A. Warraich e A. Waheed, «Does industry 5.0 model optimize sustainable performance of Agri-enterprises? Real-time investigation from the realm of stakeholder theory and domain,» *Sustainable Development,* vol. 31, n. 4, pp. 2507-2516, 2023.

[39] K. Mahroof, A. Omar, E. V. Yaroson, S. A. Tenebe, N. P. Rana, U. Sivarajah e V. Weerakkody, «Evaluating the intention to use Industry 5.0 (I5.0) drones for cleaner production in Sustainable Food Supply Chains: an emerging economy context,» *Supply Chain Management an International Journal,* vol. 29, n. 3, pp. 468-496, 2023.

[40] A. Holzinger, I. Fister, I. Fister, H. Kaul e S. Asseng, «Human-Centered AI in Smart Farming: Toward Agriculture 5.0,» *IEEE Access,* vol. 12, pp. 62199-62214, 2024.

[41] J. F. Hair, J. J. Risher, M. Sarstedt e C. M. Ringle, «When to Use and How to Report the Results of PLS-SEM,» *European Business Review,* vol. 31, pp. 2-24, 2019.

[42] P. Podsakoff, S. MacKenzie, J. Lee e N. Podsakoff, «Common Method Biases in Behavioral Research: A Critical Review of the Literature and Recommended Remedies,» *Journal of Applied Psychology,* vol. 88, n. 5, pp. 879-903, 2003.

[43] Y. Zhang, «A path to sustainable development of agri-industries: Analysis of agriculture 5.0 versus industry 5.0 using stakeholder theory with moderation of environmental policy,» *Sustainable Development,* vol. 32, n. 5, pp. 4829-4843, 2024.

[44] M. S. Ahmed, S. A. Kareem e M. M. Mustafa, «Emerging Trends Shaping the Sustainable Future of Food Industry 5.0: Challenges and Opportunities,» in *Food and Industry 5.0: Transforming the Food System for a Sustainable Future*, 2025, pp. 277-287.

[45] M. Z. Anam, M. H. Islam, M. T. Islam, A. M. Bari e A. Raihan, «A Fermatean fuzzy approach to analyze the drivers of digital transformation in the agricoltural production sector: A pathway to sustainability for emerging economies,» *Green Technologies and Sustainability,* vol. 100197, 2025.

[46] R. V. Bacter, A. E. M. Gherdan, R. Ciolac, D. P. Bacter, M. A. Dodu, M. S. Casau-Crainic, C. Gavra, A. C. Pereș, A. Ungureanu e T. Czirják, «From Heritage to Modern Economy: Quantitative Surveys and Ethnographic Insights on Sustainability of Traditional Bihor Products,» *Agriculture,* vol. 15, n. 13, 2025.

[47] G. Barbieri, F. Zapata e J. D. R. De La Torre, «Transforming Learning Environments: asset management, social innovation and design Thinking for Educational Facilities 5.0,» *Education Sciences,* vol. 15, n. 8, 2025.

[48] S. A. Bhat, N. Huang, I. B. Sofi e M. Sultan, «Agriculture-Food Supply Chain Management Based on Blockchain and IoT: A Narrative on Enterprise Blockchain Interoperability,» *Agriculture,* vol. 12, n. 1, 2021.

[49] J. Jeyabalan, K. Rohan e M. Shanthalakshmi, «Book:Food and Industry 5.0: Transforming the Food System for a Sustainable Future: Industry 5.0 Technologies for Sustainable Food Production,» in *Food and Industry 5.0: Transforming the Food System for a Sustainable Future*, 2025, pp. 155-169.

[50] M. Madhavan, M. A. Sharafuddin e S. Wangtueai, «Impact of Industry 5.0 Readiness on Sustainable Business Growth of Marine Food Processing SMEs in Thailand,» *Administrative Sciences,* vol. 14, n. 6, 2024.

[51] B. Nicoletti e A. Appolloni, «Green Logistics 5.0: a review of sustainability-oriented innovation with foundation models in logistics,» *European Journal of Innovation Management,* 2024.

[52] A. Redchuk, F. W. Mateo, G. Pascal e J. E. Tornillo, «Adoption Case of IIoT and Machine Learning to Improve Energy Consumption at a Process Manufacturing Firm, under Industry 5.0 Model,» *Big Data and Cognitive Computing,* vol. 7, n. 1, 2023.

[53] D. Sangarathas e S. Shanmugathas, «Human-Centric Digital Transformation in Industry 5.0: A Phenomenological Study of Family-Owned SME in Sri Lanka,» *The Electronic Journal of Information Systems in Developing Countries,* vol. 91, n. 4, 2025.

[54] G. Sedrakyan, A. Gavai e J. Van Hillegersberg, «Design Implications Towards Human-Centric Semantic Recommenders for Sustainable Food Consumption,» *Lecture notes in computer science,* pp. 312-328, 2023.

[55] C. Siemieniuch, M. Sinclair e M. Henshaw, «Global drivers, sustainable manufacturing and systems ergonomics,» *Applied ergonomics,* vol. 51, pp. 104-119, 2015.

[56] H. Stern, R. Diedrich e M. Freitag, «Cognitive Assistance Systems in Intralogistics: A User Study on the Effects of Varying Levels of Customization,» *IFAC-PapersOnLine,* vol. 58, n. 19, pp. 1102-1107, 2024.

[57] V. Vidric, C. Paulus, S. Grebner, M. Treiber, M. Mayr e A. Mandler, «Re/upskilling the agricultural labour force: Micro-credentials as innovative LLL strategy,» *European Society for Engineering Education (SEFI),* 2023.

[58] M. Wang, Y. Tong, C. Zhuang e X. Du, «Towards industry 5.0: A framework of reconfigurable matrix-structured manufacturing system,» *Journal of Manufacturing Systems,* vol. 82, pp. 114-136, 2025.

[59] L. Zhao, Y. Liu, M. He, D. Zhang, H. Liu e B. Sun, «From Industry 4.0 to 5.0: Exploring the opportunity of Biodegradable Freshness indicator packaging,» *Comprehensive Reviews in Food Science and Food Safety,* vol. 24, n. 4, 2025.

Appendix 1. Food industry 5.0 questionnaire

Section 1. General information

1. In which industry sector are you currently working?

   ☐ Food
   ☐ Beverage
   ☐ Packaging

2. In which department do you mainly work?
   ☐ Production
   ☐ Quality control
   ☐ Logistics
   ☐ Maintenance
   ☐ Administration
   ☐ Other (specify) ___________

3. How many years have you worked in the food sector?
   ☐ Less than 1 year
   ☐ 1–3 years

☐ 4–7 years
☐ 8–15 years
☐ More than 15 years

4. What is the approximate size of your company?
☐ < 50 employees
☐ 50-249 employees
☐ 250-1000 employees
☐ > 1000 employees

5. In which country are you currently employed?

☐Italy
☐Germany
☐France
☐UK
☐Spain
☐Other (specify)_________

Section 2 - Knowledge and perception of Industry 5.0

[Likert scale 1-5: 1 = Strongly Disagree / 5 = Strongly Agree]

6. I believe I know the concept of “Industry 5.0.
7. My workplace includes technologies typically associated with Industry 4.0/5.0 (e.g., collaborative robots, artificial intelligence, IoT sensors, digital twins, automated systems).

Section 3 - Technologies exposure

[Likert scale 1-5: 1 = Never / 5 = Always]

8. My work involves direct interaction with machines, automated systems, or AI.
9. I have adequate training for the technologies I use on a regular basis.

Section 4 - Psychological/Cognitive Well-being

[Likert scale 1-5: 1 = Strongly disagree / 5 = Strongly agree]

10. The digital technologies I use make my work more efficient.
11. Interacting with machines or automated systems causes me stress or discomfort.
12. I find it difficult to keep up with the pace of technological change at work.
13. The increase in automation and use of robots makes me fear being replaced.
14. I believe that automation and digital technologies have reduced my sense of participation and control at work.

15. The rise of automation and the use of new technologies (e.g., AI) have reduced my job satisfaction.

Section 5 - Physical Well-being / Workplace Safety

[Likert scale 1-5: 1 = Strongly disagree / 5 = Strongly agree]

16. The technologies I use reduce the physical effort required in my work.
17. Digital technologies play an important role in creating an ergonomic work environment.
18. I believe that a workplace integrated with automated systems and digital technologies is overall safer for operators.
19. I believe that automated systems and digital technologies play an important role in reducing accidents and injuries.

Section 6 - Vision of the Future and Human-Machine Coexistence

In this section, we ask for your opinion on how technologies (sensors, digital systems, or automated tools) can be integrated into work environments while respecting workers' well-being and central role. Within the context of Industry 5.0, many companies are adopting organizational models that emphasize human-machine collaboration, non-invasive safety monitoring, worker involvement in technological decisions, and human-centered design. To avoid misunderstandings, we provide brief definitions of some concepts:

• Well-being monitoring: the use of lightweight sensors (e.g., posture, movement, physiological parameters such as heart rate or stress indicators) solely for the purpose of preventing injuries, reducing fatigue, and improving safety and comfort.
• "Human-In-The-Loop" model: an organization in which the operator always maintains control and supervision, while robots and digital systems adapt to their needs, conditions, and work pace.
• Active worker involvement: processes in which personnel are consulted (e.g., feedback, pilot tests) before introducing or modifying technologies.
• Human-centered design: approaches that place the person at the center, aiming for a balance between technological efficiency, well-being, safety, and quality of work.

The following statements aim to understand how you perceive these models, how useful you consider them, and how important you believe worker participation is in technological decision-making.
[Likert scale 1-5: 1 = Strongly disagree / 5 = Strongly agree]

20. I believe that company decisions should balance technological efficiency and worker well-being.
21. I would be in favor of monitoring posture, movements, and certain physiological parameters (such as heart rate) if used exclusively to prevent injuries, reduce stress, and improve my well-being and safety.
22. I believe it is important that any monitoring system fully respects my privacy and that I am clearly informed about how my data are collected, used, and stored.

23. I view a "human-in-the-loop" model positively when the operator maintains supervision over decisions made by digital technologies.
24. I would like to be more involved in the process of introducing or modifying technologies in the company.
25. I believe that human-centered organizational models (e.g., human-centered design, human-in-the-loop, active involvement) can improve well-being in the workplace.

Section 7 - Additional comments and consideration (optional)

26. Do you have any suggestions or personal opinions about the relationship between humans and technology in your company? (open space for free response)

Appendix 2. Survey additional comments

1. Continuous cross-functional trainings on new technologies with real financial investment behind.
2. Technology makes it possible to eliminate the most physically demanding tasks, especially for operators, and also to reduce the number of people employed in night shifts, thus helping to increase well-being and work–life balance.
3. Italian companies invest limited resources in poor and obsolete technologies. Internal competencies that would allow technological progress are lacking. As long as the entrepreneurial fabric consists mainly of SMEs, these will absorb new technologies with decades of delay. At present, this question regarding the relationship between technology and the company is not applicable.
4. Better involvement arises from continuous and targeted training.
5. It is an essential activity to find the best possible way to integrate and benefit from technological development.
6. Do not force the replacement of human activity with technological processes.
7. The greatest challenge in the introduction of new technologies is preserving and improving workers' well-being. Probably the most difficult and central task should be handled by the human resources department in change management, also addressing older workers who are less inclined toward change.
8. There should be more training for staff.
9. It would be important to implement it, even just for monitoring health parameters; however, it proves difficult for some more sensitive age groups.
10. I believe that training, at all levels, is the foundation for creating progress in the technological world. It is necessary to conduct an analysis of current problems and then think about possible technological solutions. Finally, if new technologies are implemented, people must be trained.
11. More training is needed.
12. Sharing objectives and training.
13. It's very important that the technologies guarantee a data driven approach in order to improve the industrial efficiency and resilience.
14. I believe it is essential to educate entrepreneurs about the technology in question.
15. In my context, human "know-how" is still predominant. Technological support is nevertheless fundamental for the correct management of processes and allows human

experts to focus more on essential aspects and on those peculiarities that become a competitive advantage.

16. In my company, given the type of product, there is a large manual component where humans truly make the difference and where machines can only support certain phases of the process. However, I believe that technology, if properly applied, can always be efficient without replacing humans and the added value of their contribution.
17. Certainly, where production is standardized, automation will perform at 100%. In my sector, introducing automation at critical points (e.g., refrigerated automated warehouses) involves significant risks in order fulfillment. In my company, I would have approached automation while always keeping the possibility of manual processing for emergencies.
18. Still too underdeveloped, even though it is considered a step toward a significant improvement in results. Moreover, the geographical factor (being located in Italy) appears to influence technological development and human–machine integration understood as human-in-the-loop development.
19. Innovations must be properly “tailored” to different production realities; a solution that is very positive in one company could even be negative in another.
20. Technology is a tool that transforms ideas into actions and actions into possibilities.
21. Twenty-five years ago, my former owner asked me to transform the industrial production of baked goods from manual to fully automated. The result was that production waste and inefficiency decreased from 11% to 1%. Since then, I have always embraced innovation and change.
22. Do not limit human intuition, creativity, and imagination, in addition to responsible decision-making in every context.
23. Technology has the potential to help workers in general, both in jobs requiring significant physical effort and in managerial roles. Basically, if well managed, the application of technology creates physical and psychological well-being; however, if decisions made by managerial functions lead to abuse, there is a risk of unnecessarily increasing workloads for many roles without benefits, creating a chain reaction.
24. Cobots are very useful for repetitive tasks and ensure repeatability while relieving the physical strain on operators.
25. More space should be given to innovation, without fear of improvement. We should free ourselves from the idea of “this is how it has always been done, so it’s fine.” Often, generational change helps a lot.
26. There should always be a proper balance between human presence and know-how and new technologies (AI, etc.). Technology should serve humans to improve working conditions and productivity (without replacing them).
27. Technology should be used to allow us to improve our working conditions.
28. In my sector, automation may at times represent a source of operational risk, particularly in a company like ours that does not rely on inventory buffers and operates on a make-to-order basis. Our production system includes six automated warehouses located upstream of the slicing lines, as well as four palletizers supported by a customized underground material-handling system. From a maintenance standpoint, system failures can generate significant operational stress, especially during time periods when service coverage is limited. Most critically, any stoppage of the automated warehouses directly results in a halt in production activities.